

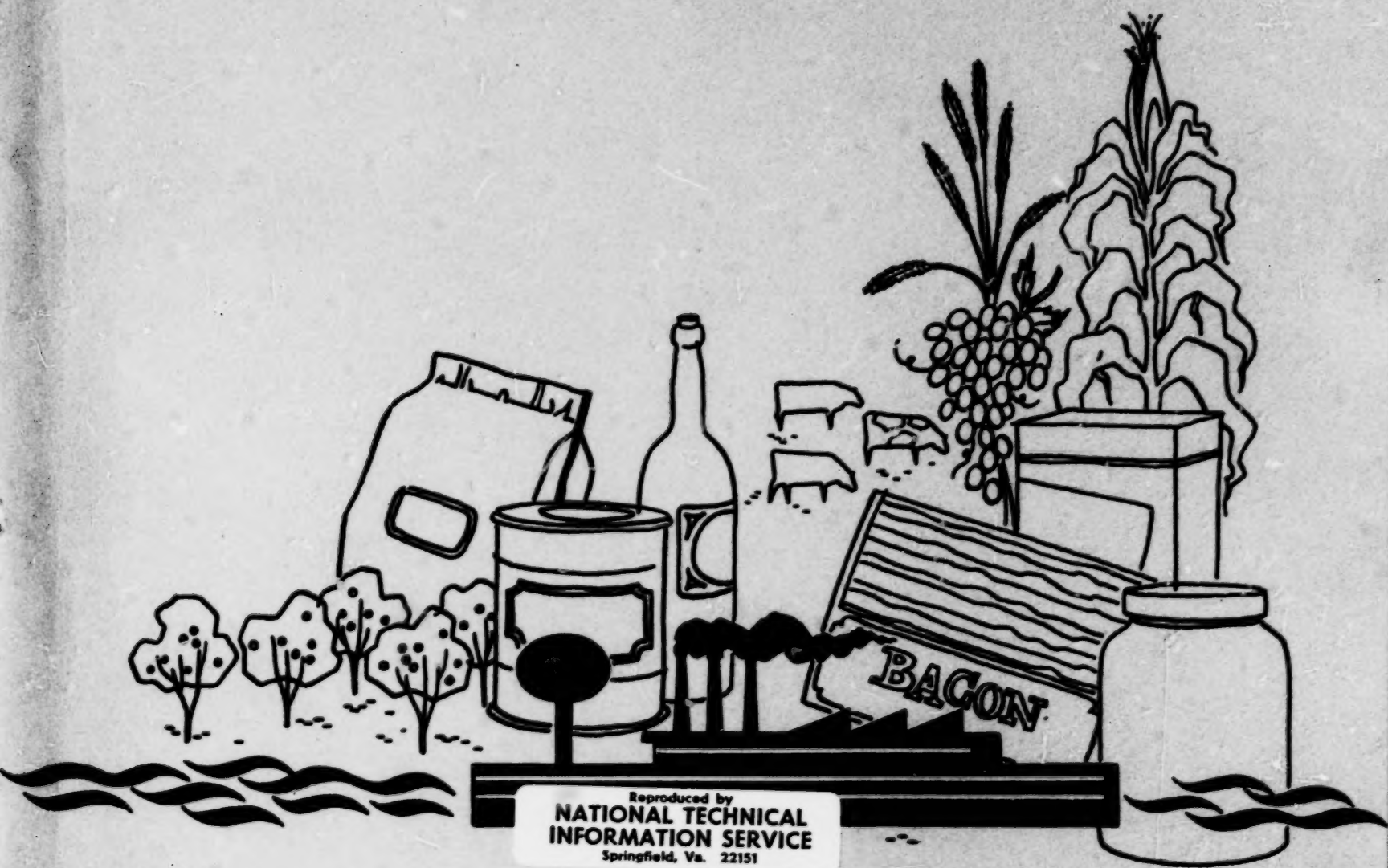


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Cannery Waste Treatment Kehr Activated Sludge



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27 Abstract The Kehr modification of the activated sludge process uses a completely mixed aeration tank with no intentional solids wasting. After the aeration tank stabilized at between 4000 and 12,000 mg/l of MLSS, a 40 day investigation using municipal and cannery wastes of strengths from 200 to 2000 mg/l BOD ₅ was conducted. 90% BOD ₅ and 80% TOC reductions were achieved, but little or no reduction was detected in nitrates and phosphates and the effluent was colored and turbid. Periods of little or no loading for as long as 48 hours caused no decrease in treatment efficiency when flow was resumed. From the above information, KASP was recognized as being well suited to industrial waste pre-treatment prior to discharge to a municipal treatment plant. The ability to handle intermittent flows provide 90% BOD ₅ removal, and provide aerobic digestion of solids in the aeration tank is essential for pre-treatment devices and all are possessed by KASP. Exclusive of primary treatment, treatment of 10 mgd of a 250 mg/l BOD ₅ waste would cost 7¢/1000 gallons using gravity settling. Because of operational problems and high power demand, the use of the electroflotation instead of gravity settling would increase costs to 29¢/1000 gallons treated. In each instance, however, the variability of industrial wastes demands pilot plant studies to determine actual design criteria and cost estimates. (Lowry-Texas)

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Cannery Waste Treatment
Kehr Activated Sludge

by

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for the

FEDERAL WATER QUALITY ADMINISTRATION
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September 1970

FWQA Review Notice

This report has been reviewed by the Federal Water Quality Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Quality Administration, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The Kehr Activated Sludge Process (KASP), as practiced at FMC Corporation's Central Engineering Laboratories, uses a completely mixed aeration tank with no intentional sludge wasting. The concentration of mixed liquor suspended solids was allowed to stabilize at some value as a result of cellular synthesis, endogenous loss, and washout in the effluent. The concentration of mixed liquor suspended solids ranged from 4,000 to 12,000 mg/liter. The BOD₅ of domestic sewage and cannery wastes varied from 200 to 2000 mg/liter.

Removals obtained were 80 percent reduction in the concentration of total organic carbon and 90 percent reduction in the concentration of BOD₅.

The process was able to undergo a 48-hour period of no organic loading with no loss of treatment efficiency when the organic load was returned. The KASP appears to have an application for pretreatment of industrial wastes prior to discharge to a municipal sewer. The KASP, when used in this manner, could handle intermittent waste discharge, produce 90 percent BOD₅ removal and provide aerobic digestion within the aeration tank.

Exclusive of any primary treatment, the cost of treating 10 mgd of a waste containing 250 mg/liter of BOD₅ using this high solids activated sludge process is about 7¢ per thousand gallons using gravity settling and about 29¢ per thousand gallons using electroflotation. The cost of pretreating 1 mgd of a waste containing 2,000 mg/liter BOD is about 28¢ per thousand gallons exclusive of primary treatment.

This report was submitted in fulfillment of Grant 12060 EZP between the Federal Water Quality Administration and the FMC Corporation.

Key Words: Cannery wastes, industrial waste pretreatment, activated sludge process, aerobic digestion, electroflotation.

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SECTION I

CONCLUSIONS

The use of the Kehr Activated Sludge Process (KASP) for treatment of domestic sewage and high strength cannery wastes was successfully demonstrated. Aerobic digestion was obtained in the aeration tank of a completely mixed activated sludge plant at aeration times from 2 to 8 hours.

This process does not remove phosphorus or significant quantities of nitrogen since solids are not intentionally wasted but appear in the effluent stream. Although 90 percent BOD₅ removal can be obtained for high strength wastes, the effluent would not be satisfactory for discharge to bodies of water in many areas. Thus, a potential application of the process is for pretreatment of high strength industrial wastes prior to discharge to a municipal sewer system. The KASP has the ability to withstand long periods of little or no organic loading without a substantial loss of efficiency when loading is resumed.

It was determined that electroflotation is technically but not economically feasible for this application. Power costs and costs for electrode replacement are excessive. Electroflotation may have application for very small scale treatment systems and for thickening but cannot compete with sedimentation for large scale systems.

From results of this study, large scale demonstration of the KASP for pretreatment of high strength industrial wastes prior to discharge to a municipal sewer system is indicated. Because of the large differences in BOD removal rate constants for various industrial wastes, it is considered desirable to operate a pilot plant to determine design parameters for each waste.

SECTION II

INTRODUCTION

The activated sludge process is used for treating a variety of industrial wastes; however, these wastes often cause problems because of their seasonal nature and their shock loading effect on a conventional treatment plant by way of sudden high strengths or flows. Examples of such wastes are cannery, meat packing or processing, dairy, paper mill, and textile plant effluents. Adequate processing is needed to overcome such treatment difficulties.

An adaptation of the activated sludge process that appears to be capable of processing high strength wastes has been studied in Europe and uses high concentrations of mixed liquor suspended solids with little sludge wasting. This adaptation, which was a parallel development to extended aeration, is the Totalklaranlage developed by Professor Dietrich Kehr of the Technische Hochschule in Hanover, Germany (1) and consists of an activated sludge with a concentration of mixed liquor suspended solids of 10,000 to 14,000 mg/liter and aeration time of 6 hours. Kehr has reported high removals of BOD₅, nitrogen, and phosphorus with a loading of about 94 pounds of BOD₅/1000 ft³ of aeration tank. The high solids concentration of the process when coupled with physical conditions capable of maintaining a proper environment comprises an inherent buffering capability for high strength waste, but at times, also causes operating difficulties in the liquid-solids separation of the activated sludge in the final tank.

The basic objective of the investigation reported herein was to demonstrate reliable performance of an adaptation of the activated sludge process using high concentrations of mixed liquor solids. The FMC Corporation has termed this the "Kehr Activated Sludge Process" (KASP). This system treated both domestic sewage and cannery wastes having BOD₅ strengths of 200 to 2000 mg/liter. Flotation for solids separation and densification as well as gravity sedimentation was studied to determine processing requirements for application to full-scale treatment plants.

This report describes the tests conducted to determine the effectiveness of the KASP for treating domestic sewage and cannery wastes. It also includes the cost estimates for a 10 mgd KASP treatment plant using either gravity sedimentation or electroflotation for solids separation.

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SECTION III

TEST FACILITY AND EQUIPMENT

Permanent Facility

The permanent facility at FMC's Central Engineering Laboratories (CEL) Environmental Engineering site includes a 12" diameter inlet sewer from an 18" diameter sanitary sewer serving part of the City of Santa Clara. An adjustable hinged gate has been provided in the 18" line to divert sewage into the test site. A pumping station which receives the sewage from the 12" line is provided with two parallel open channels in which various forms of screening and comminution are available. Any one or all of the two channels and the 12" line may be closed off and emptied if desired. At the present time, a standard Chicago Pump comminutor serves one channel and a production prototype Barminutor machine the other.

All sewage, whether directly from the sewer, screened, or comminuted, flows into a wet well located beneath the channels and comminuting equipment. In an adjacent dry well are two centrifugal pumps for delivering the sewage from the wet well through a six-inch pressure line to an elevated flow splitter located in an outdoor test area. Valving in the dry well permits direct pumping back to the city sewer downstream from the point from which it was withdrawn. Maximum delivery to the elevated splitter is 750 gpm with both pumps running. A portion of the total flow to the splitter is diverted to a settling cone where grit and a portion of the suspended solids are removed. The overflow from this settling tank flows to another splitter box where it can be directed to sites throughout the test facility. A schematic diagram illustrating the CEL facilities is shown in Figure 1.

Experimental Facilities

A schematic drawing of the activated sludge system used for the KASP study is shown in Figure 2. The primary components of the system consisted of an aeration tank with a liquid volume of about 120 gallons and a circular sedimentation tank four feet in diameter.

Mixed liquor was pumped from the aeration tank to the final clarifier by a positive displacement pump driven by a variable speed motor. The flow rate was controlled by the speed of the motor. The return sludge was also pumped by a positive displacement pump and the flow rate was set equal to the settled sewage flow rate by a timer controlling the percentage of the time the pump was on. A float switch controlled the settled sewage flow.

A diurnal flow variation was produced by a 24-hour program timer, which controlled the power to the mixed liquor and return sludge pumps

FIGURE 1



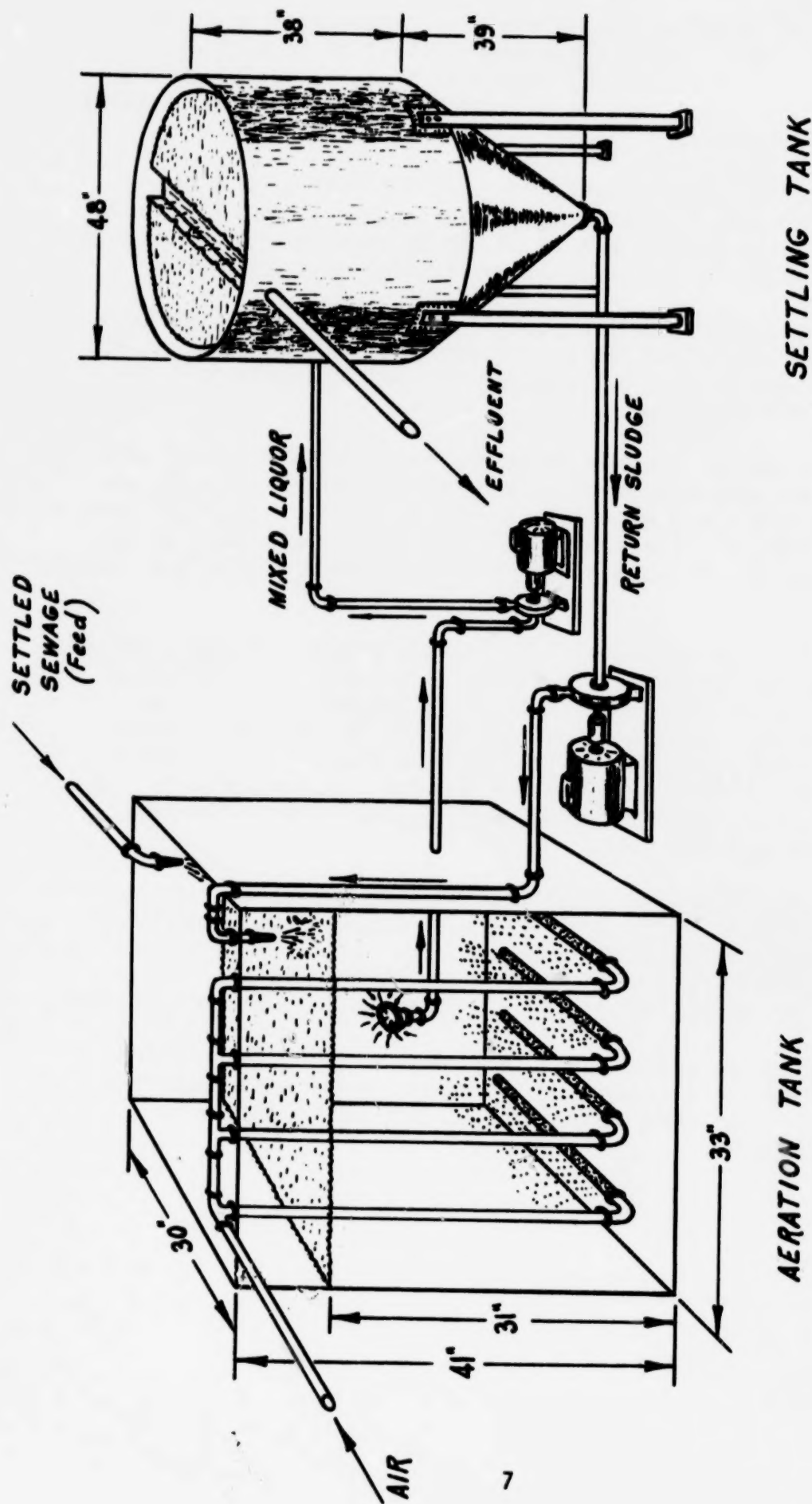


FIGURE 2

KEHR ACTIVATED SLUDGE PLANT

S.S.

for each 5-minute interval during the day. Flow patterns similar to that at the San Jose - Santa Clara Water Pollution Control Plant were produced by controlling the number of 5-minute cycles during each hour that the pumps were on and off. The diurnal flow patterns used are shown in Figure 3.

Oxygen was supplied by a blower which pumped air through 4 carborundum diffusers, each 3 inches in diameter and 24 inches long. The air flow was varied from 16 CFM to 30 CFM to maintain the concentration of dissolved oxygen in the mixed liquor greater than 2 mg/liter.

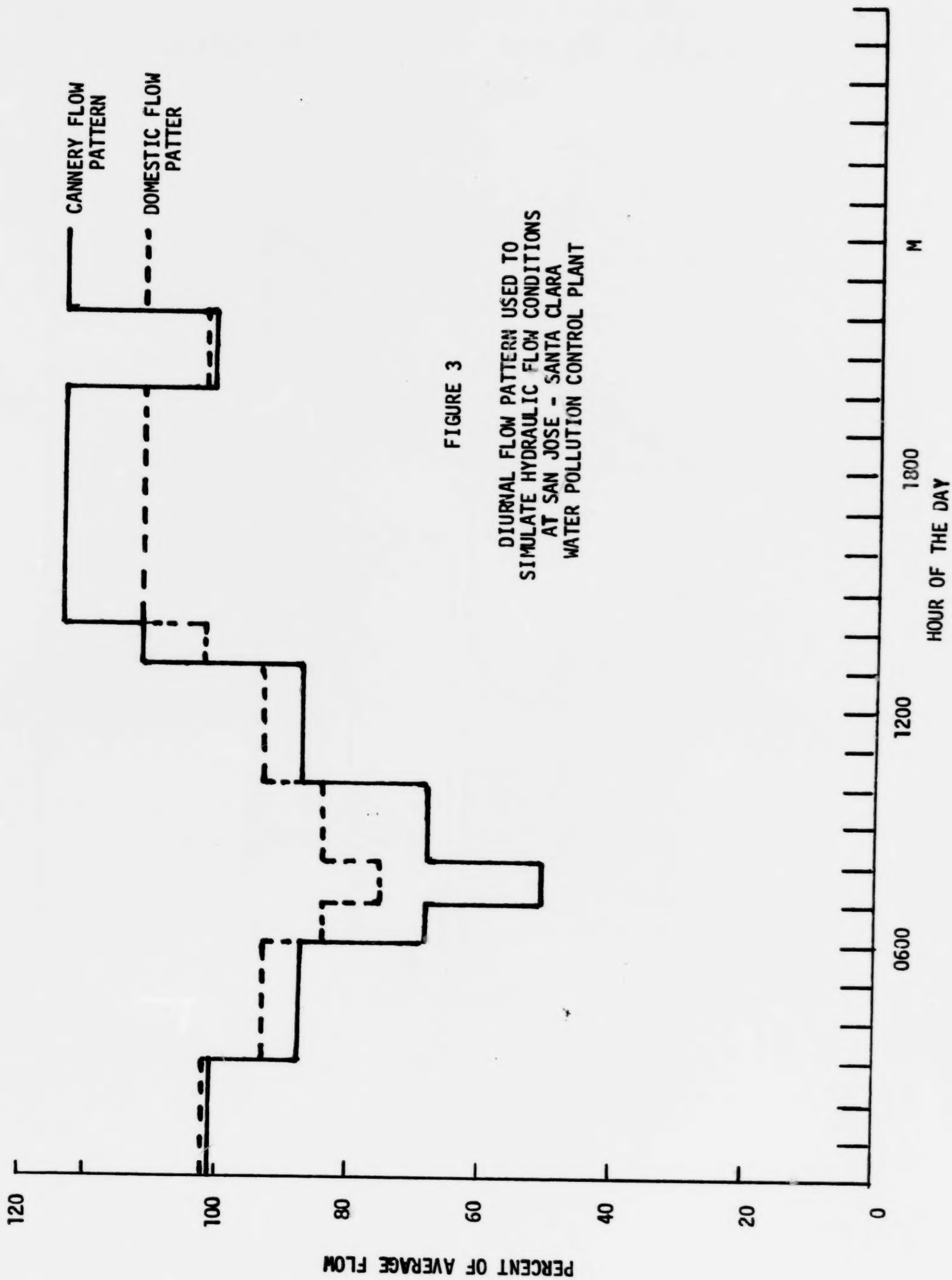
The principal equipment used to study the electroflotation of KASP mixed liquor was the flotation cell shown in Figure 4. Within this cell, both the gas production required for the separation and the separation itself took place.

The cell has a central chamber where the gas and mixed liquor were introduced and a majority of the separation occurred. The gas was produced by 50 stainless steel electrodes 2" x 3/32" x 15-1/2" that alternated as cathode and anode. Electrodes were placed at the bottom of the chamber as shown in Figure 4 and current was supplied by a D.C. power supply.

Mixed liquor from the KASP aeration tank was pumped through a cross-shaped distributor above the electrodes by a positive displacement pump driven by a variable speed motor. The mixed liquor solids then contacted the rising gas bubbles which could become attached causing the solids to rise towards the upper liquid surface where a sludge blanket formed. This sludge blanket was periodically swept with a vacuum head to remove the floated solids which were returned to the aeration tank.

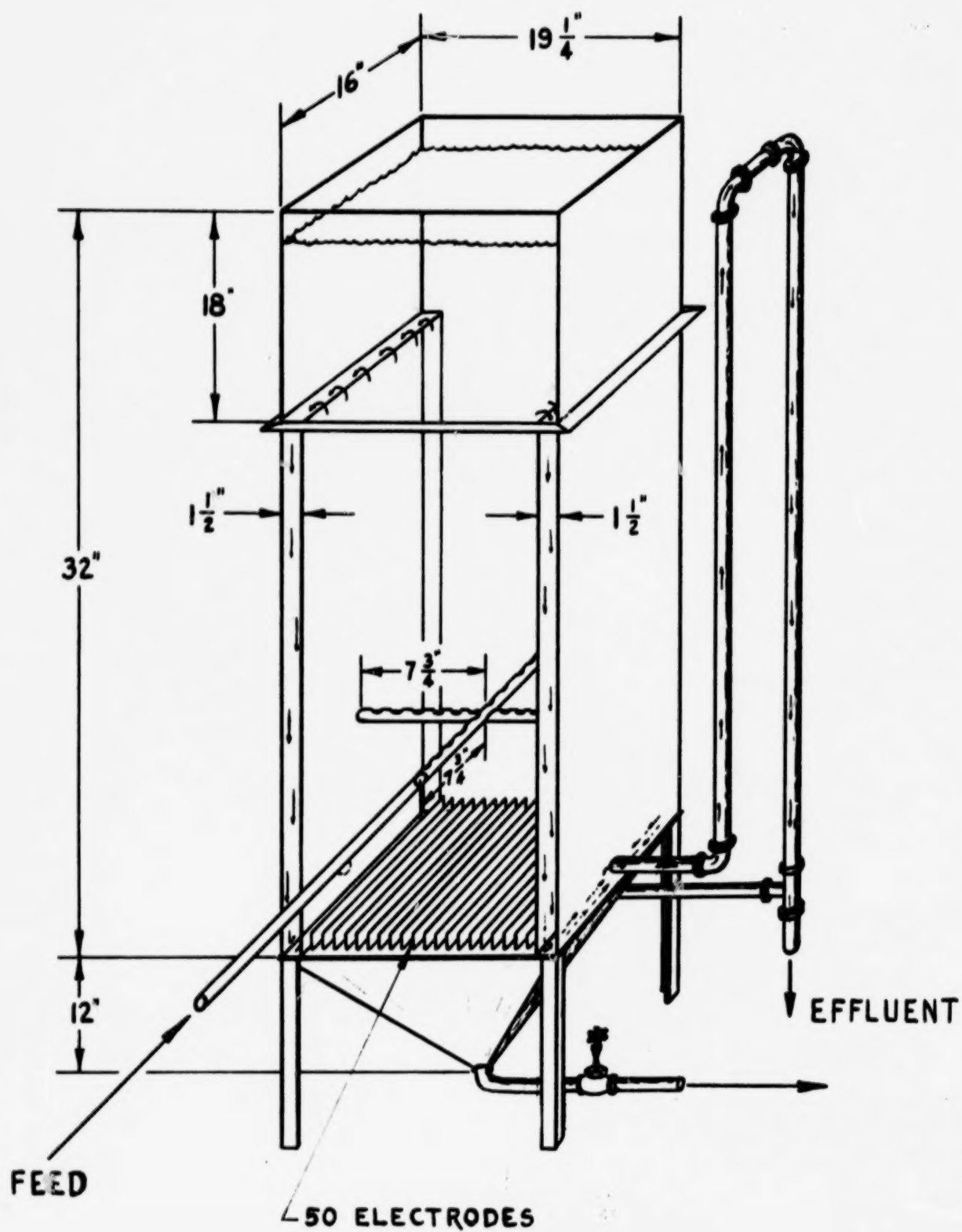
The liquid flow was up the center channel from the feed distributor and then down the side channels. Those solids with attached bubbles that were washed over into the side channels were able to float free because of the quiescent conditions in the side channels. The remainder of the solids carried over were washed out in the effluent.

The electroflotation system was tested on a portion of the mixed liquor overflow stream because of its experimental nature whereas gravity settling was used on the main stream due to its known reliable performance.



CONTINUOUS FLOW FLOTATION CELL

FIGURE 4



SECTION IV

EXPERIMENTAL PROGRAM

The experimental program was separated into two studies. One was the study of various aspects of the biological system and the other was the study and evaluation of electrofloation for the separation of mixed liquor solids to produce a clear effluent.

Biological System

The study of the biological system included two main parts: a study of continuous operation of the KASP treating sewages of various strengths and a study of the response to an artificially imposed shock loading situation.

Besides these main studies, a tracer washout study to determine whether the aeration tank was completely mixed, and a study to determine the diurnal variation of sewage strength were conducted.

Flotation System

The study of the flotation system was conducted to determine the amount of gas required to effect a given separation. This information could then be coupled with information on power requirements obtained previously (2) to develop costs for a full scale plant.

Laboratory Analyses

Analyses used in the evaluation of the KASP and related separation process were done in accordance with "Standard Methods for the Examination of Water and Wastewater", Twelfth Edition, and included the following:

Suspended Solids	SS
Volatile Suspended Solids	VSS
Total Solids	TS
Total Volatile Solids	TVS
Sludge Volume Index	SVI
Five-Day Biological Oxygen Demand	BOD ₅
Organic Nitrogen	O-N
Ammonia Nitrogen	NH ₃
Nitrate Nitrogen	NO ₃
Nitrite Nitrogen	NO ₂
pH	

Analyses for total organic carbon (TOC) were performed using a Beckman Carbonaceous Analyzer, Laboratory Model, and all total phosphate analyses utilized a sulfuric acid - nitric acid wet oxidation procedure followed by Standard Methods for orthophosphate analyses.

SECTION V

EXPERIMENTAL PROCEDURE

Tracer Washout Study

To determine if the KASP aeration tank was completely mixed, a tracer washout study was performed by first filling the aeration tank with fresh water. Then a concentrated sodium chloride solution was pumped into the aeration tank. The effluent was periodically sampled and the concentration of the chloride was determined as a function of time. The chloride concentration in the effluent from a completely mixed tank can be expressed mathematically by the following equation:

$$\log \frac{C_F - C_E}{C_F - C_I} = -Dt \quad (1)$$

Where: C_F = Feed concentration,
 C_E = Effluent concentration,
 C_I = Initial concentration in the system,
 D = Tank displacement per unit time, and
 t = Time.

Biological System

The KASP was operated at a return sludge rate of 100 percent. This was accomplished by adjusting the return sludge flow rate to one-half the flow rate of mixed liquor to the final tank. Since no sludge was intentionally wasted, the only other control required was to maintain the flow of air in sufficient quantity to maintain the mixed liquor dissolved oxygen about 2 mg/liter. Both the sewage and effluent were sampled every hour during the 8:00 AM to 5:00 PM working day for an eight-hour composite. The mixed liquor and return sludge were samples on a grab basis.

A programmed study was conducted to determine the performance of the high solids activated sludge system under shock loading conditions. This was designed to simulate shocking caused by a sudden decrease followed by a sudden increase in sewage strength. The underloading shock was simulated by changing the feed to the aeration tank from sewage to fresh water. After 48 hours, the feed to the aeration tank was changed back to sewage so that an overloading shock occurred. A constant feed was begun for one week prior to the test to insure that a steady state condition existed at the start of the test. Grab samples were taken of mixed liquor, return sludge, final effluent, and the sewage feed.

Flotation System

To evaluate the electroflotation of the KASP mixed liquor, the EF cell was first filled with clear water. The power supply was then turned on and the current between the electrodes set at the desired value. After the central chamber was filled with a fine mist of bubbles rising from the electrodes, the mixed liquor pump was started and set at the desired flow rate. After at least two hydraulic detention times, the effluent, mixed liquor, and occasionally the return sludge were sampled. The amperage and the mixed liquor flow were measured and recorded. After sampling, the conditions were changed to begin a new run.

SECTION VI

RESULTS

Tracer Washout

The degree of complete mixing of the aeration tank was determined by adding a sodium chloride solution (3400 mg/liter as Cl^-) to the aeration tank at a flow rate of 2.0 gpm, which resulted in a liquid detention time of 59 minutes. Effluent samples were analyzed for chloride and these data as well as the theoretical washout curve are plotted in Figure 5. The observed data points follow the theoretical curve very closely indicating that the aeration tank was completely mixed.

The data from the tracer washout also demonstrated the ability of a completely mixed aeration tank to buffer shock loadings as compared to a plug flow tank. The salt solution fed to the KASP aeration tank was a hundred times as concentrated as the fresh water initially in the tank. As the strong salt solution was added, it was immediately dispersed throughout the aeration tank, which resulted in a gradual increase in the salt concentration in the aeration tank. The washout data demonstrating this buffering phenomena are shown graphically in Figure 6. In a plug flow tank, the hundred-fold increase would not be dispersed throughout the tank and would move through the tank as a highly concentrated core of salt water. If a hundred-fold increase occurred in sewage strength, this same buffering phenomena of the completely mixed aeration tank would allow the microorganisms in the mixed liquor to react to a slowly changing environment rather than any sudden shock that would be experienced in a plug flow tank.

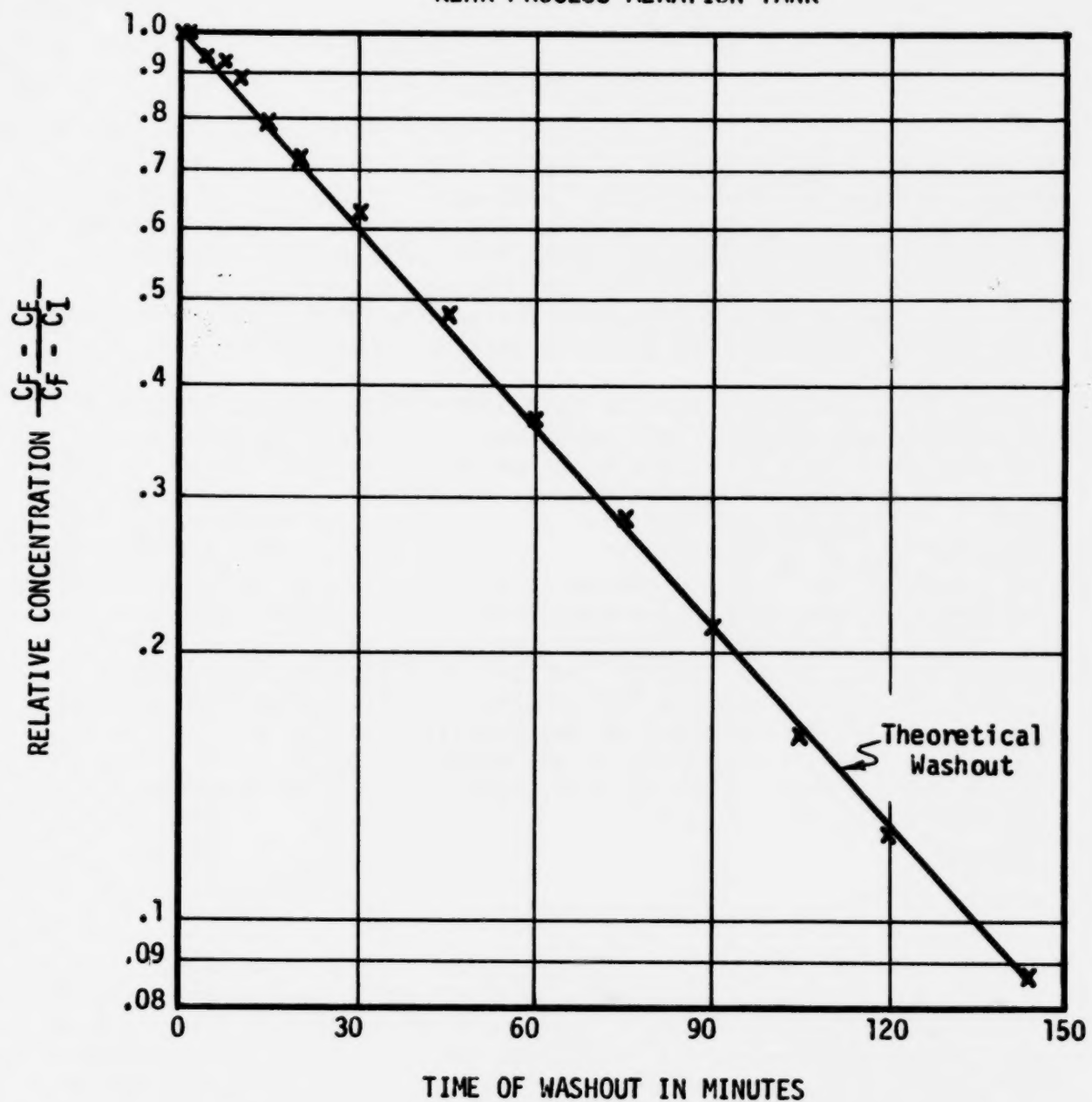
Continuous Operation of KASP

The KASP, as operated at CEL, had no solids removed from the system as a waste sludge stream. Therefore, the KASP could only remove carbonaceous matter and nutrients from the liquid waste by converting them to a gaseous form. Carbon, nitrogen, and phosphorus were the materials measured in this study and the removal of each of these by the KASP is presented in the following results.

The KASP was operated continuously for 28 days during the fall of 1967 and for 12 days during the fall of 1968. Because the canneries did not usually pack on weekends, the sewage during the canning season was characterized by high concentrations of BOD_5 from Monday to Friday and low BOD_5 domestic waste on the weekend. After the canning season, the sewage, which primarily consisted of domestic waste, had a fairly constant concentration of BOD_5 throughout the week.

Data showing the performance of the KASP stabilizing organic waste are

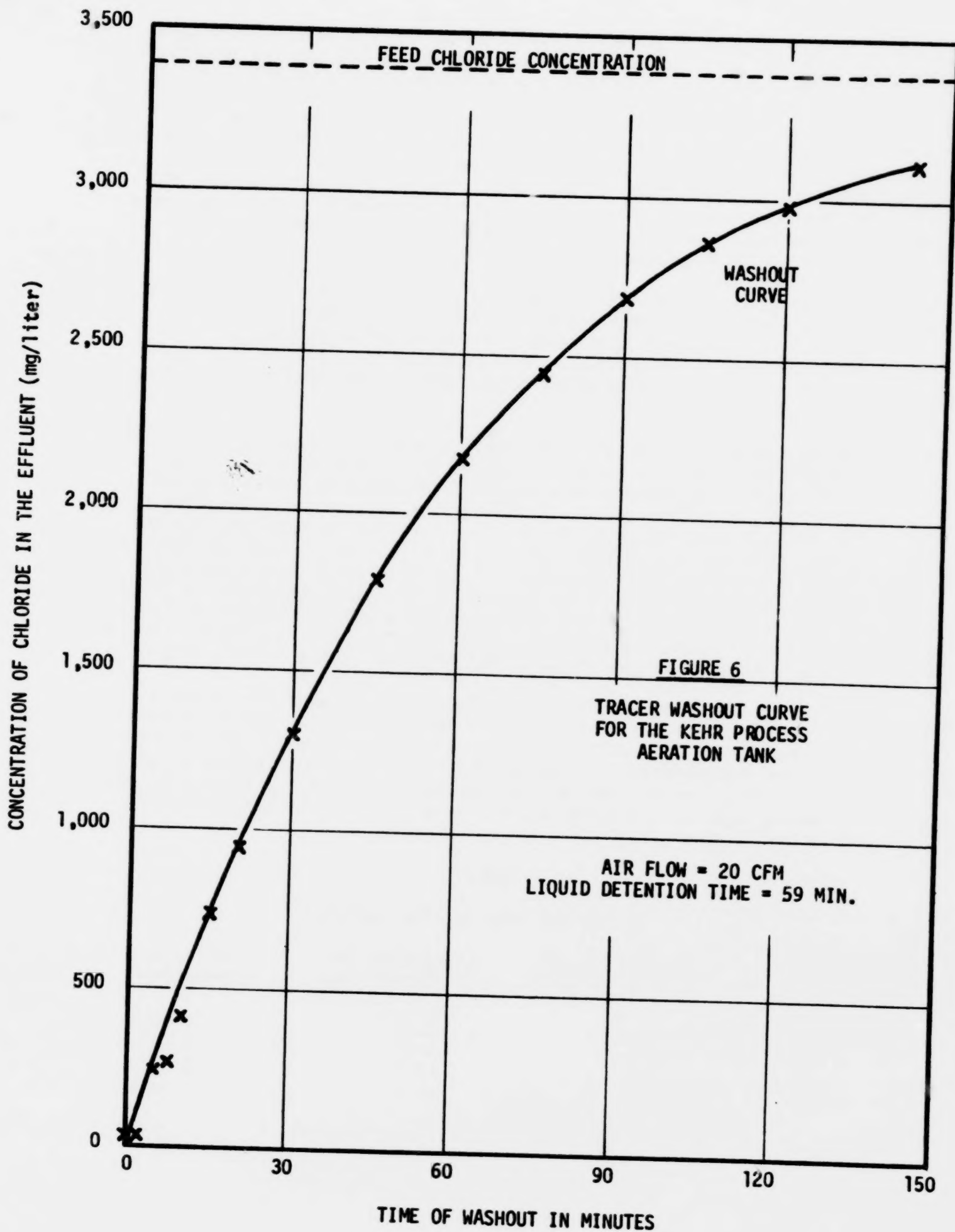
FIGURE 5
TRACER WASHOUT CURVE FOR THE
KEHR PROCESS AERATION TANK



C_F = Feed Concentration

C_E = Effluent Concentration

C_I = Initial Concentration in Tank Before Test



shown in Figures 7 and 8. Figure 7 shows the TOC data while Figure 8 shows the data for BOD₅. On weekdays during the canning season, the KASP treated cannery wastes with concentrations of BOD₅ ranging up to 1550 mg/liter and achieved over 90 percent BOD₅ removal and 80 percent TOC removal. However, on the weekends the sewage strength decreased while the concentration in the effluent of both BOD₅ and TOC remained at about the same level as during the week. This caused a reduction in the percent removals of both TOC and BOD₅ during the weekends. The most illustrative example of this phenomena was Sunday, September 8, 1968, where the percent removal of BOD₅ dropped to 28.4 and the percent removal of TOC dropped to -48.4.

This nearly constant effluent quality was due in part to the inverse of the washout phenomena shown in Figure 6. Another factor that probably contributed to the nearly constant effluent quality is that the BOD₅ in the effluent is affected by the efficiency of the solids separation system which is somewhat independent of the influent BOD.

During the period when the KASP treated domestic sewage, the influent and effluent qualities were fairly constant yielding constant percent removals of carbonaceous materials measured as either BOD₅ or TOC. Because of the consistent sewage quality, the only shocking of the KASP came from the diurnal flow variation programmed into the system. During one 24-hour period, the biological system was sampled every hour. Four-hour composites of the feed and effluent were made up and analyzed for TOC. The results of this test are shown in Figure 9. These data show that the KASP produced a very consistent effluent by damping out the variation in loading due to flow in a manner similar to that observed for the organic shocking during the canning season.

Based upon the 8-hour composite samples, the BOD₅ and TOC removals for each aeration period tested were calculated. The percent removals were calculated by summing the total amounts of BOD₅ and TOC in both the feed and effluent for each aeration period rather than on a daily basis. These percent removals are presented in Table 1 along with the number of days of operation at each aeration period. Detailed test data are in the appendix.

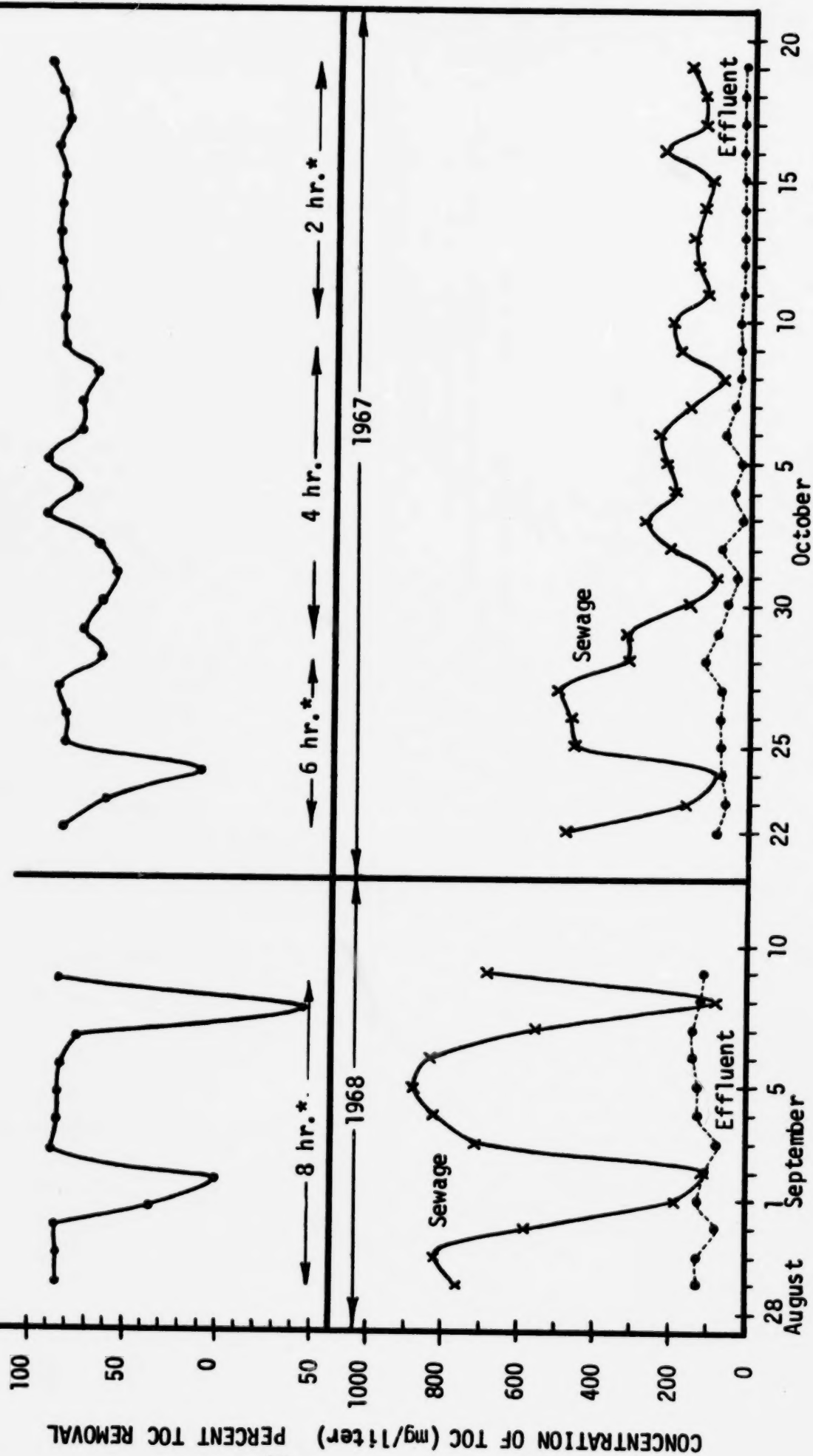
TABLE 1

CUMULATIVE BOD₅ AND TOC REMOVALS

<u>Aeration Period</u>	<u>Cumulative BOD₅ Removal (%)</u>	<u>Cumulative TOC Removal (%)</u>	<u>Period of Operation</u>
8 hours	88.9	80.2	11 days
6 hours	84.4	77.2	7 days
4 hours	85.7	77.1	9 days
2 hours	95.3	87.4	11 days
AVERAGE	88.5	80.4	

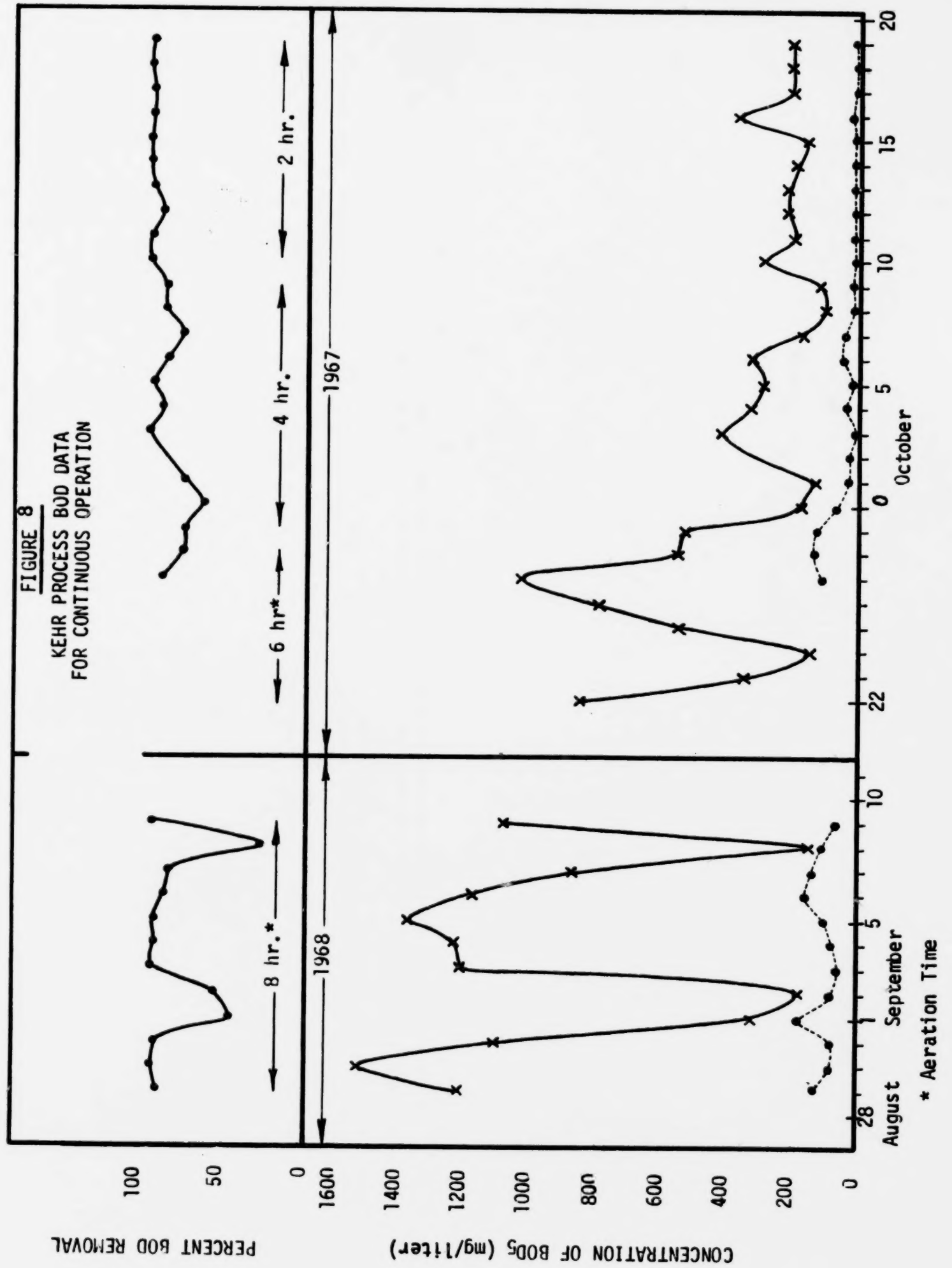
FIGURE 7

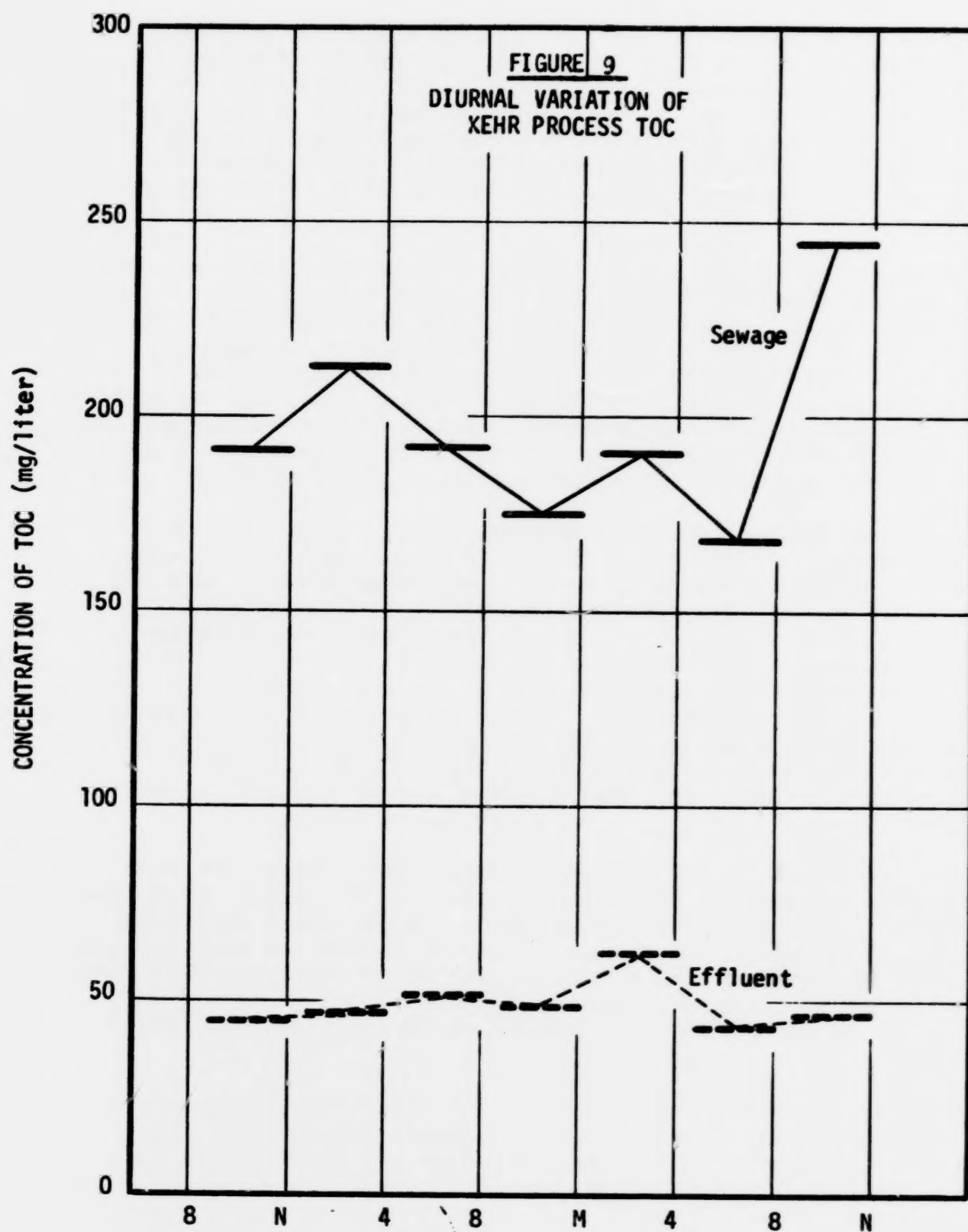
TOC DATA FOR THE KEHR PROCESS
FOR CONTINUOUS OPERATION



* Aeration Time

FIGURE 8
KEHR PROCESS BOD DATA
FOR CONTINUOUS OPERATION





DATE 10/10 and 10/11/68

HOUR OF THE DAY

10/10 MLSS = 11,580

MLVSS = 9,560

10/11 MLSS = 13,230

MLVSS = 10,900

2 HOUR AERATION TIME

The operation of the KASP was such that the changes in aeration period coincided with changes in sewage strength and character resulting from seasonal fluctuations in cannery operation. For this reason as well as the short period of operation at each aeration period, the results at different aeration periods cannot be compared directly. However, removals of about 80 and 90 percent for TOC and BOD₅, respectively, do give some indication of the treatment efficiency of the KASP.

When designing a particular activated sludge treatment plant, one of the most important design parameters is the loading rate. Three different loading parameters were calculated from the data for the operation of the KASP and are given in Table A-4 in the appendix. The three are: the volumetric loading measured as the pounds of BOD₅ per day per thousand cubic feet of aeration tank, and two forms of the organic loading measured as the pounds of BOD₅ per day per pound of mixed liquor suspended solids, and as the pounds of BOD₅ per day per pound of mixed liquor volatile suspended solids.

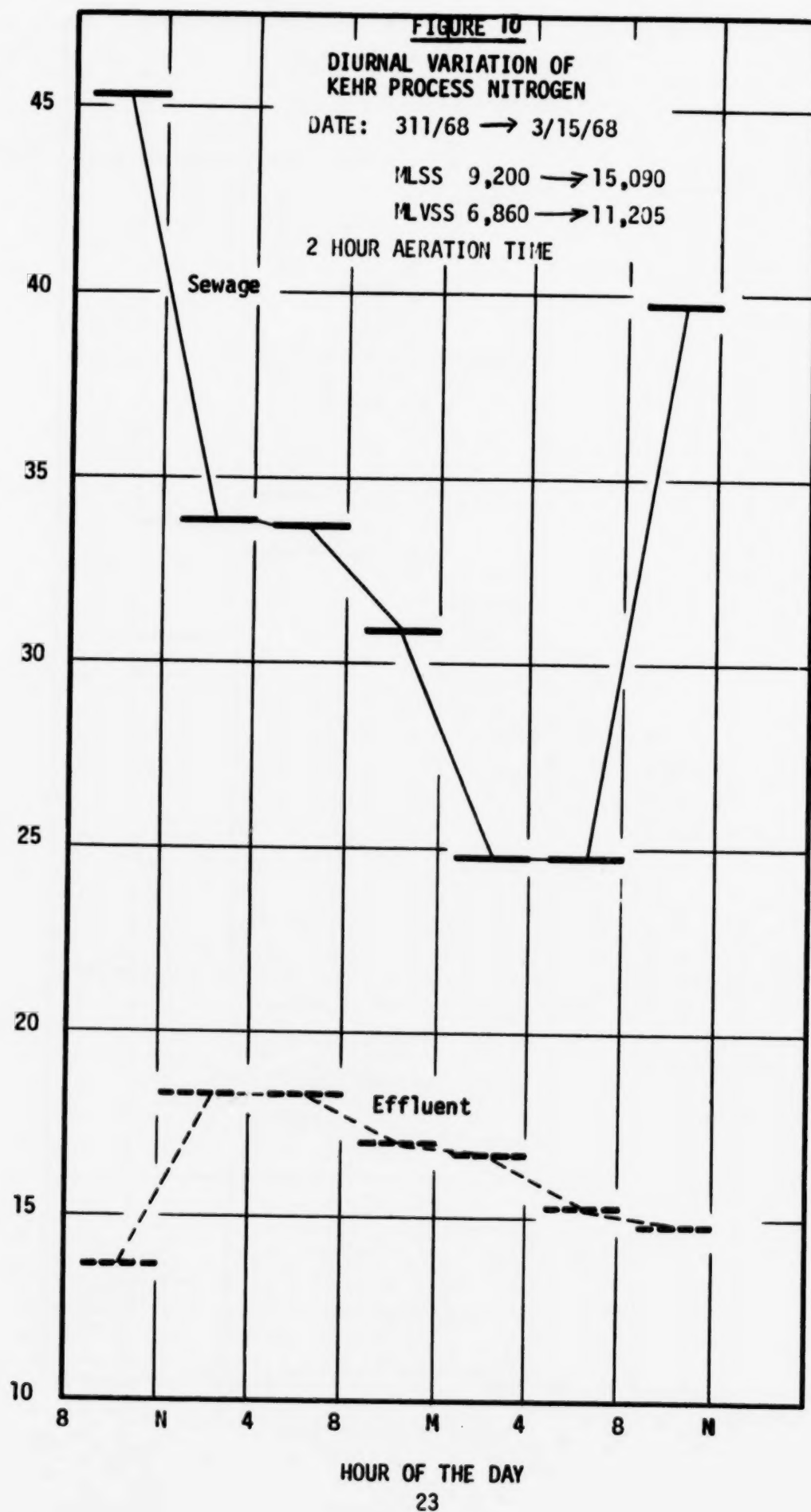
The various loading parameters were not constant due to the lack of steady state conditions. For the KASP with no intentional sludge wasting, the observed average loading, excluding weekends, were 200 pounds of BOD₅ per day per thousand cubic feet of aeration tank capacity, 0.473 pounds of BOD₅ per day per pound of mixed liquor volatile suspended solids, and 0.418 pounds of BOD₅ per day per pound of mixed liquor suspended solids. For the purpose of this report, the average volumetric loading was used as the design parameter for scale up. It should be noted that the mixed liquor suspended solids were high in volatile matter. They were 85 to 90 percent volatile matter which is higher than the 75 percent found for many wastes.

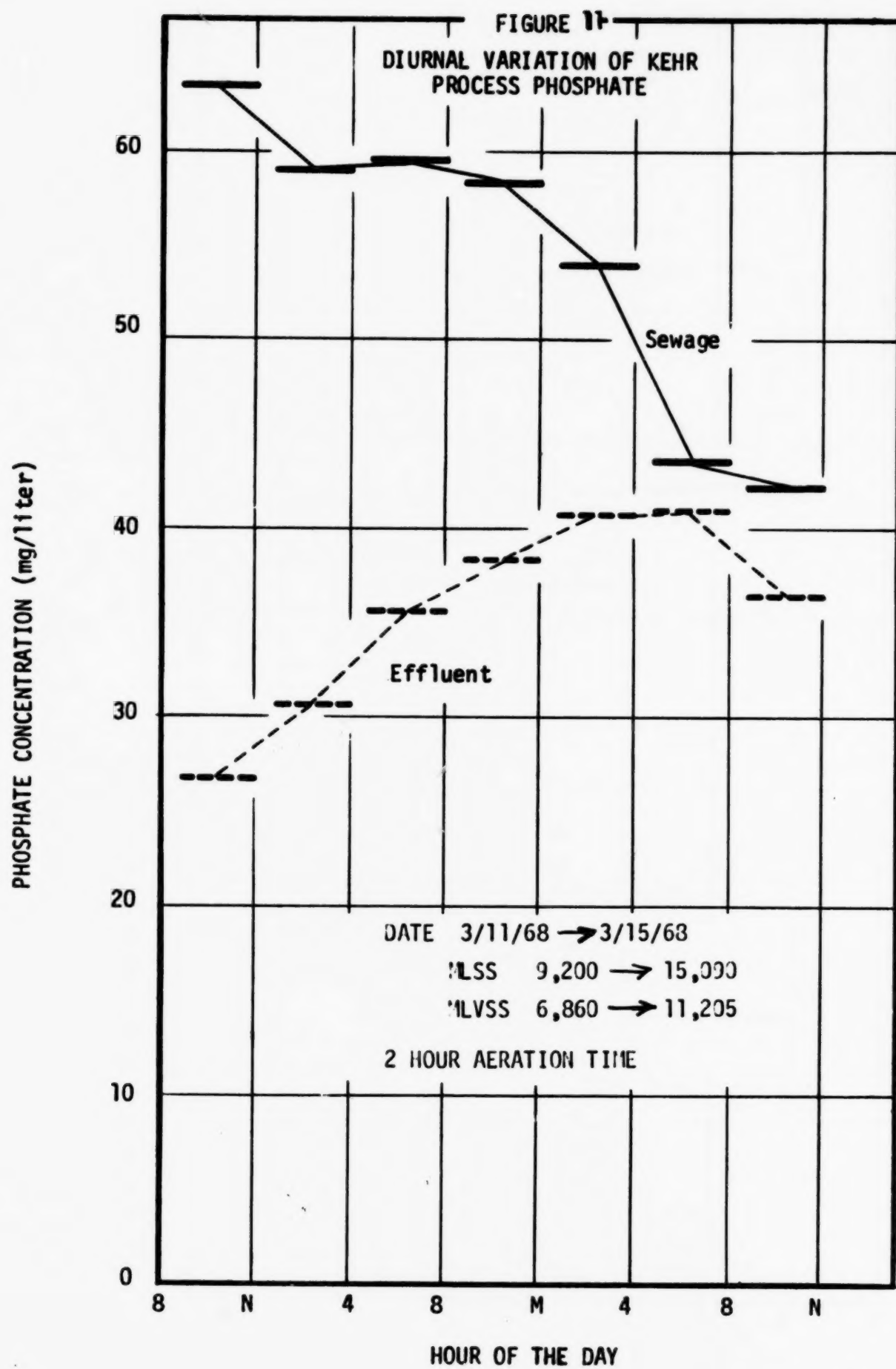
Data on the influent and effluent phosphate and nitrogen are shown in Tables A-X to A-XII in the appendix. Because the system was sampled only during the eight-hour working day, balances around the system could not be made due to diurnal variations in flow and waste strength. Another factor that would affect balances is the short period of time the system was operated at each loading condition. It is possible that the system was not stabilized before loading conditions were changed.

For operation of the activated sludge process without sludge wasting, there is no mechanism for phosphorus removal. Some removal of nitrogen could occur by release of nitrogen gas to the atmosphere. A complete balance for nitrogen would not be possible without analyzing the composition of all gases.

A 28-hour sampling program was conducted on the KASP effluent and sewage in an attempt to provide more complete phosphate and nitrogen balances around the KASP. Grab samples of sewage and effluent were taken every hour and made up into four-hour composites. The results are shown in Figures 10 and 11.

TOTAL CONCENTRATION OF NITROGEN (mg/liter)





For both nitrogen and phosphate, the difference between the concentration in the sewage and that in the effluent decreased through the first 24 hours. Then during the first 4 hours of the second day this difference increased again. At no time was it possible to complete a nutrient balance. The apparent removals of nitrogen and phosphate must be explained by the factors discussed above.

Artificial Shock Loading

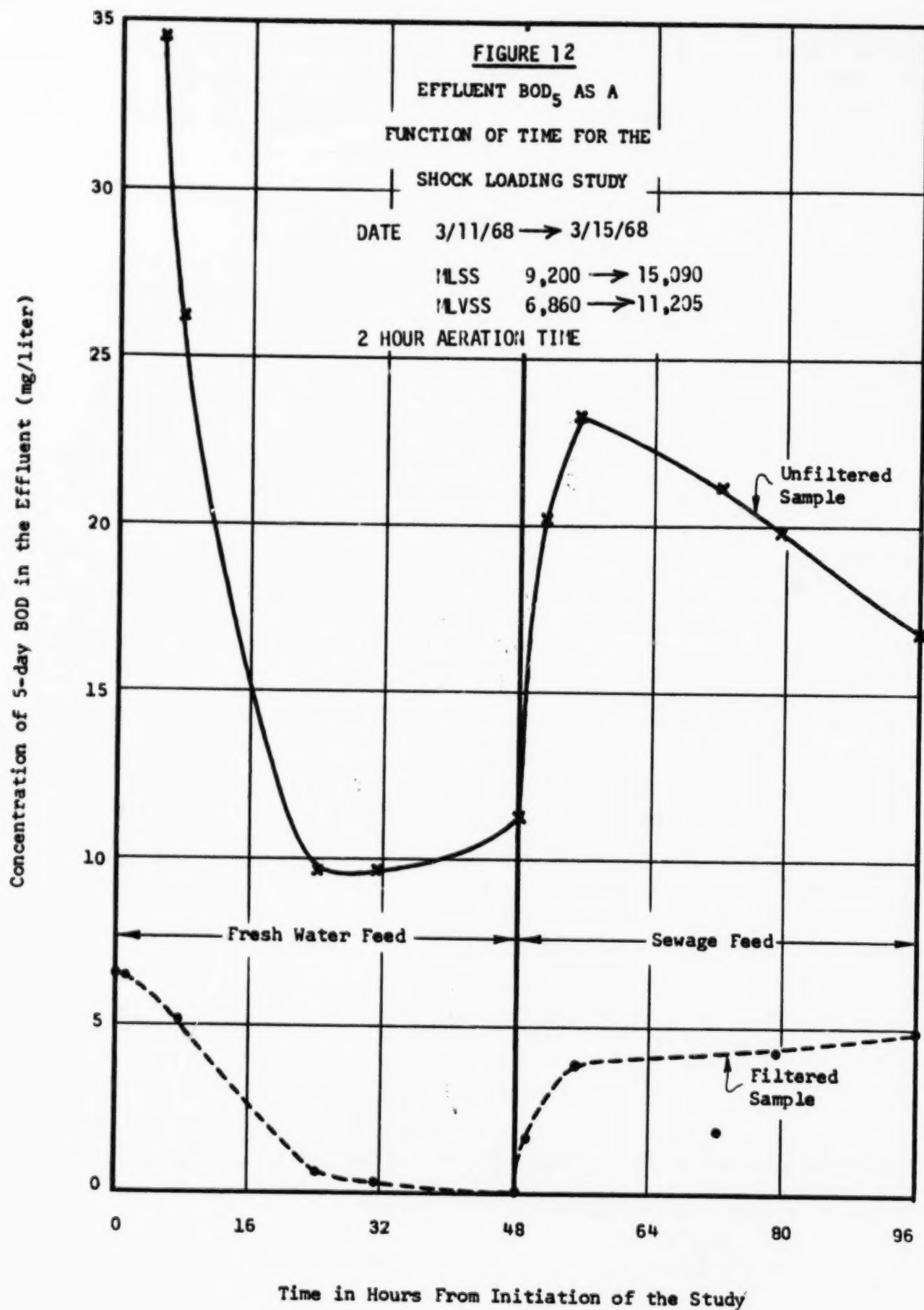
To better study the effect of shock loading conditions on the KASP, an artificial shock loading was imposed on the system. For 48 hours fresh water was fed to the system and then sewage (BOD_5 of 230 and 180 mg/liter) was fed for the following 48 hours. The aeration time was 2 hours. The response of the biological system to the artificial shock loading as measured by the effluent concentrations of BOD_5 , TOC, and suspended solids is shown in Figures 12 through 14. During the water feed, there was a washout of the various constituents from the aeration tank. The concentrations decreased rapidly and then appeared to level off. Therefore, due to the washout phenomena, the fresh water feed improved the effluent quality over that prior to the study.

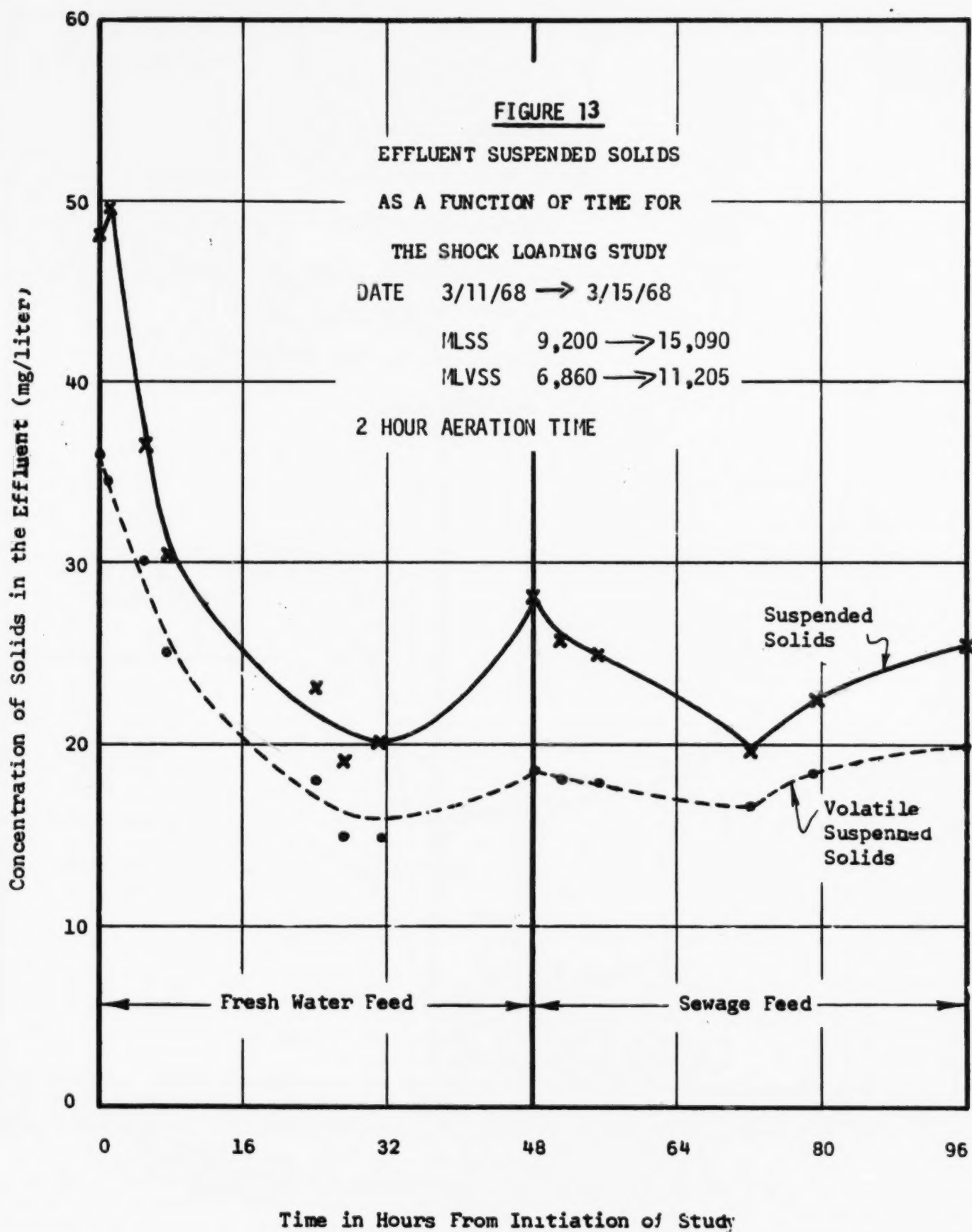
The concentration of BOD_5 in the filtered effluent dropped to nearly zero (Figure 12) indicating that little biodegradable substrate was present in solution. Because no food for the bio-mass was present in solution, the production of new cellular mass was reduced causing cell death and lysing to predominate over synthesis. The concentrations of TOC, BOD_5 , and suspended solids in the effluent after they leveled off probably corresponded to loss in the effluent due to cell lysing.

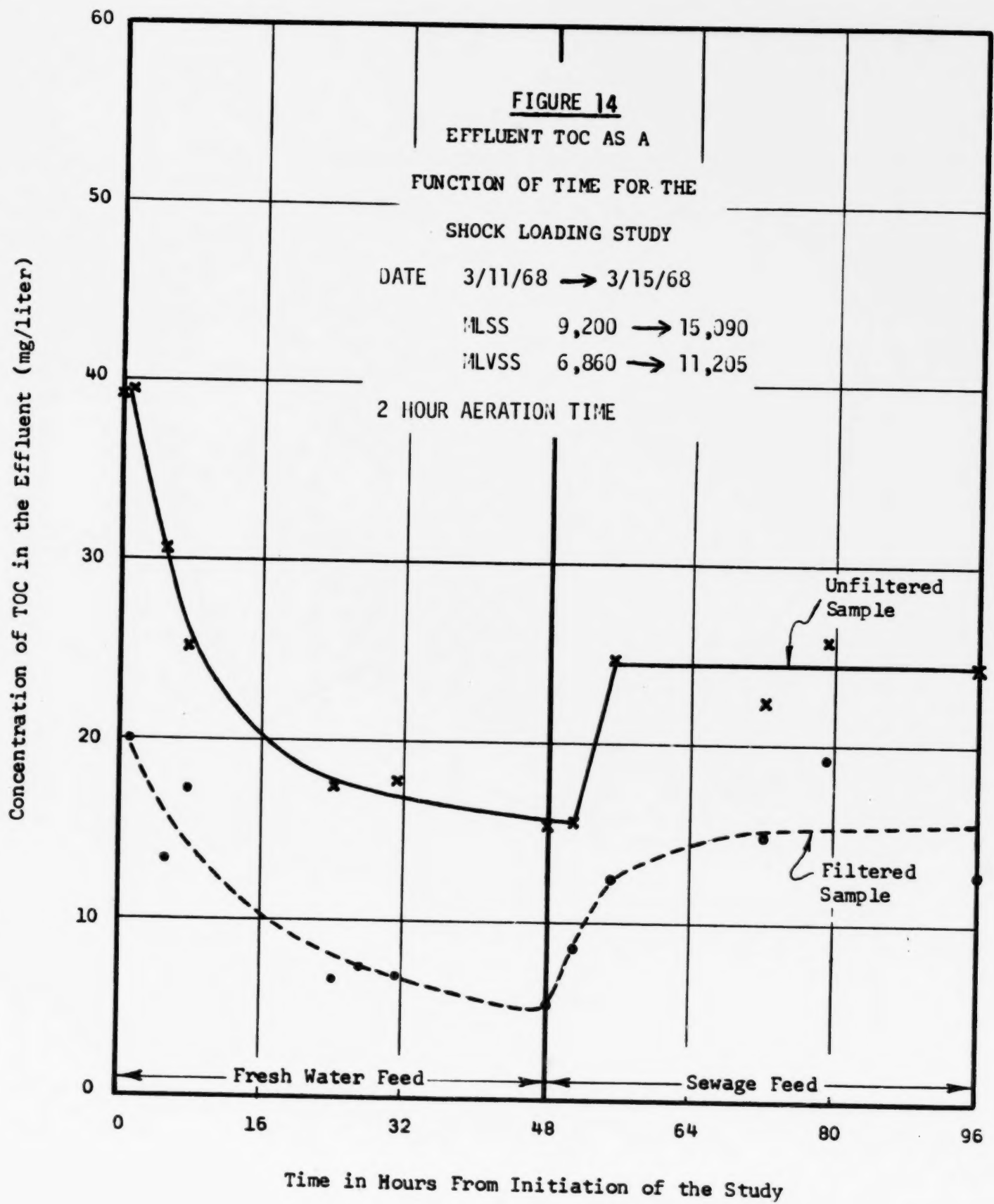
After the sewage was turned back on, a rapid and immediate increase was observed in the effluent concentrations of both the BOD_5 and TOC. This rapid increase was followed by a leveling off of the TOC and filtered BOD_5 . The filtered BOD_5 and TOC reached a level nearly the same as that before the initiation of the water feed while the level of unfiltered TOC was less than before the water feed. The concentration of unfiltered BOD_5 decreased after the initial rapid increase. The sewage feed produced little change in the concentration of suspended solids.

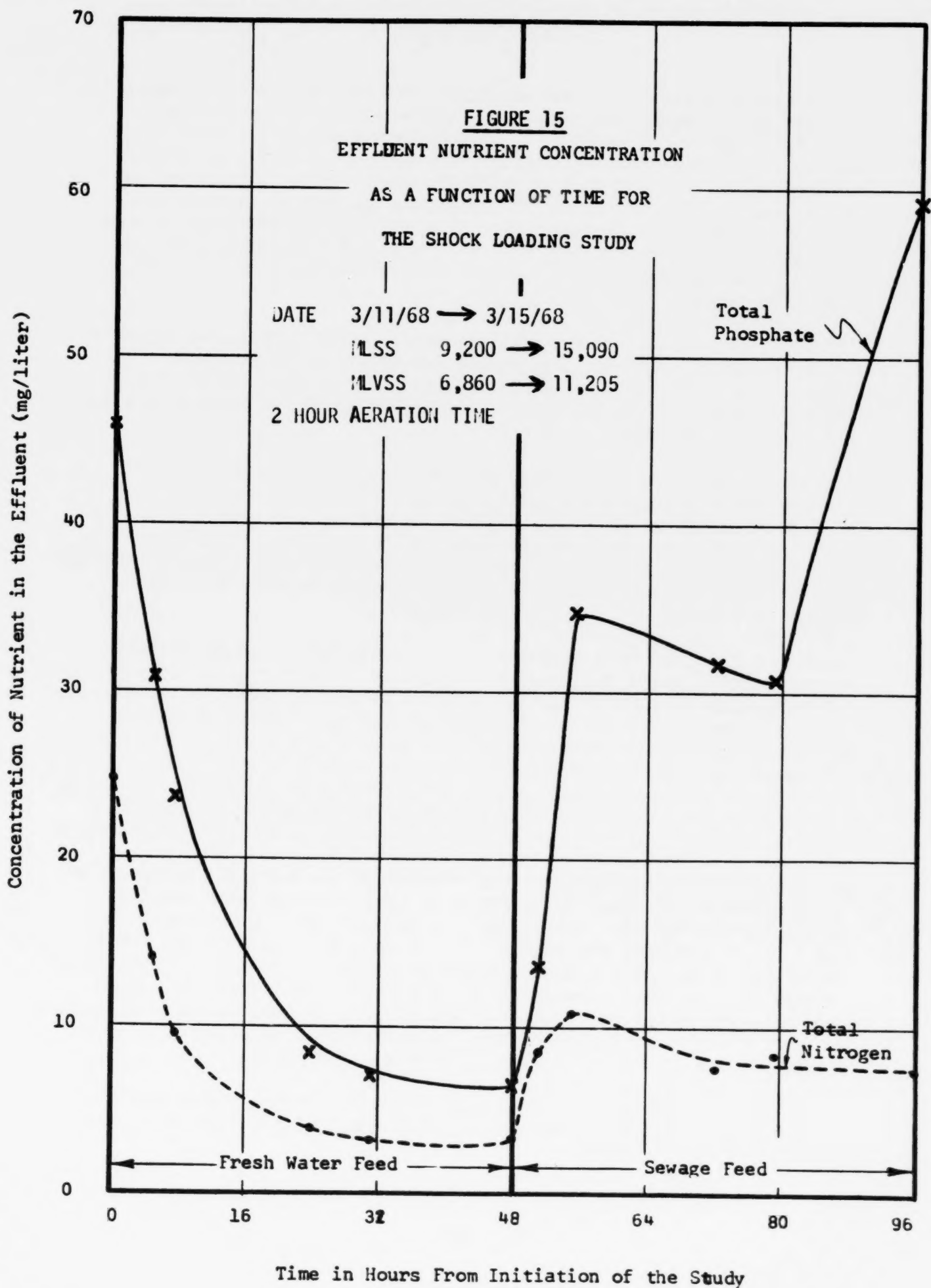
It is interesting to note that the KASP was able to go without any organic loading for 48 hours with no apparent loss of treatment efficiency when the organic load was returned. The KASP seems to be able to adequately handle wastes of periodic discharge.

The shock loading also had an effect, shown graphically in Figure 15, on the concentration of nitrogen and phosphate in the effluent. During the fresh water feed, the concentrations of both decreased rapidly to a fairly steady state value probably corresponding to the rate of cell lysing. Upon the initiation of the sewage feed, the concentrations of both increased rapidly but the concentration of nitrogen soon leveled off well below the concentration prior to the water feed.









Flotation System

The electroflotation cell was operated from May 31, 1968, to August 6, 1968, on mixed liquors ranging in suspended solids concentrations from 2,120 to 10,080 mg/liter. Sewages processed by the KASP during the initial portion of the study were of domestic origin and during the latter half were primarily cannery waste. The principle effort was devoted to removal of suspended solids, no attempt was made to maximize the concentration of solids in the thickened sludge. The results show, Figure 16, the relationship of the amount of gas generated per gram of solids to the ratio of influent to effluent suspended solids.

The plots show that the mathematical model presented in the Appendix is approximately obeyed. Two curves are shown in this figure. The upper curve is for mixed liquors that had high sludge volume indexes and were easy to float while the other curve is for sludges with a low SVI that were difficult to float.

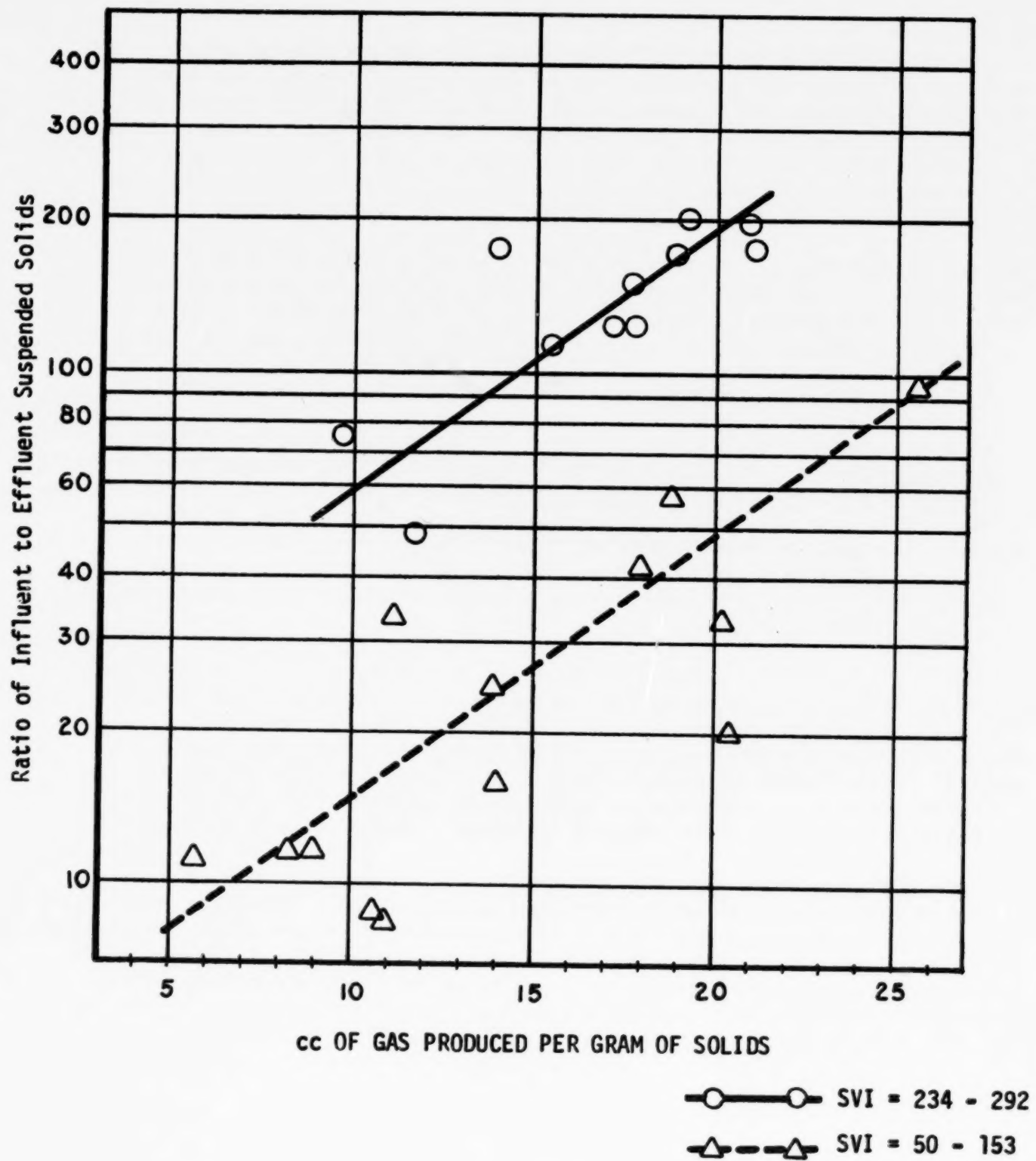
The mixed liquors that yielded the lower curve were primarily from cannery waste and appeared to have a small floc size. This meant more floc particles would be required to make up the same sludge mass than would be required for larger size particles therefore more bubble-floc attachments would be required. These extra attachments require more gas per gram of solids and therefore, make the sludge harder to float.

To obtain data for cost estimates for the electroflotation of KASP mixed liquors, these data were extrapolated to performance corresponding approximately to gravity sedimentation. Secondary gravity clarification of KASP mixed liquor containing about 10,000 mg/liter of suspended solids produced an effluent containing about 20 mg/liter of suspended solids on domestic sewage and with cannery wastes, the effluent suspended solids were about 100 mg/liter. Extrapolating the two curves to the corresponding ratio of influent to effluent solids, the gas requirements are about 28 cc of gas per gram of solids for either waste.

Although the concentration of the floated solids was not studied, the floated solids appeared to increase in concentration upon standing. In one particular case, no sludge was removed from the flotation cell for 5 hours allowing the sludge blanket to compact and drain. Under these conditions, the sludge blanket attained a concentration of total solids of 11 percent. However, in most cases the concentration of total solids in the return sludge was about 3 percent compared to about 2 percent for gravity sedimentation. Electroflotation provided a denser sludge so the volume of recycled sludge would be less.

While the EF cell was operating, gravity settling was being used to handle a majority of the KASP mixed liquor. This provided for a more

FIGURE 16
DATA FOR THE ELECTROFLOTATION OF
KEHR PROCESS MIXED LIQUORS



stable operation of the KASP aeration tank in case of power failures or other process upsets. Also, parallel operation allowed a comparison of gravity settling with electroflotation of the same mixed liquor at similar hydraulic loadings. Table 2 shows the data from parallel performance.

Electroflotation Costs

Electroflotation has two major costs which must be considered when evaluating its use for secondary solids separation. These costs are the operating costs such as power and labor and the capital costs for such things as tankage and electrodes. The labor and tankage costs are similar to those for gravity settling and will be discussed in the section on economic evaluation. However, the power and electrode costs are unique to electroflotation and will be discussed here.

The power consumed in electroflotation is used primarily to generate gas bubbles by electrolysis of water. Each coulomb of current passed between the electrodes generated 0.174 cc of gas. The volume of gas required per gram of solids to achieve a given separation can be found experimentally as shown in Figure 16. This information can then be used to calculate the current required to effect the desired separation.

Since the power is equal to the product of the voltage and the current, power requirements for electroflotation depend upon the voltage required to overcome the resistance of the electroflotation cell. This resistance is the sum of the resistance of the external circuit and the resistance of the water between the electrodes. The voltage across the external circuit is relatively constant from cell to cell whereas the voltage between the electrodes is governed by solution conductivity, electrode spacing, and the current density or electrode area.

Increasing the current density in the cell increases the cell resistance and therefore is used as a design parameter. The effects of the mixed liquor conductivity and the electrode spacing on the relationship between current density and cell voltage are presented in Figures 17 and 18. Both figures show that electrolysis of water with a lead dioxide stainless steel electrode system is initiated between 2.8 and 3.0 volts. Beyond 3 volts, the current density increases linearly with voltage.

The first figure shows that as the conductivity increases, the voltage required to produce a given current density decreases. Therefore, the higher the conductivity of the mixed liquor, the lower the power consumption at a given current density. The second figure shows that as the electrode spacing decreases, the voltage required to produce a given current density also decreases. Therefore, the minimum possible electrode spacing and the highest possible conductivity would require the minimum voltage.

TABLE 2
COMPARISON OF ELECTROFLOTATION WITH SEDIMENTATION

Mixed Liquor Suspended Solids (mg/liter)	SVI	Electroflotation			Sedimentation		
		Hydraulic Loading gal/day-ft ²	gas/solids ratio cc/g	Eff. SS*	Eff. SS*	Hydraulic Loading gal/day-ft ²	Eff. SS*
3480	258	250	21.0	20	20	303	20
3230	285	250	19.4	36	27	298	27
3460	265	250	15.4	40	39	303	39
3955	234	214	17.6	26	17	303	17
3785	244	230	17.1	30	19	298	19
3360	247	800	11.6	68	19	303	19
6470	147	510	5.6	574	29	308	29
4675	---	250	15.8	47	29	322	29

* Effluent Suspended Solids in mg/liter

FIGURE 17

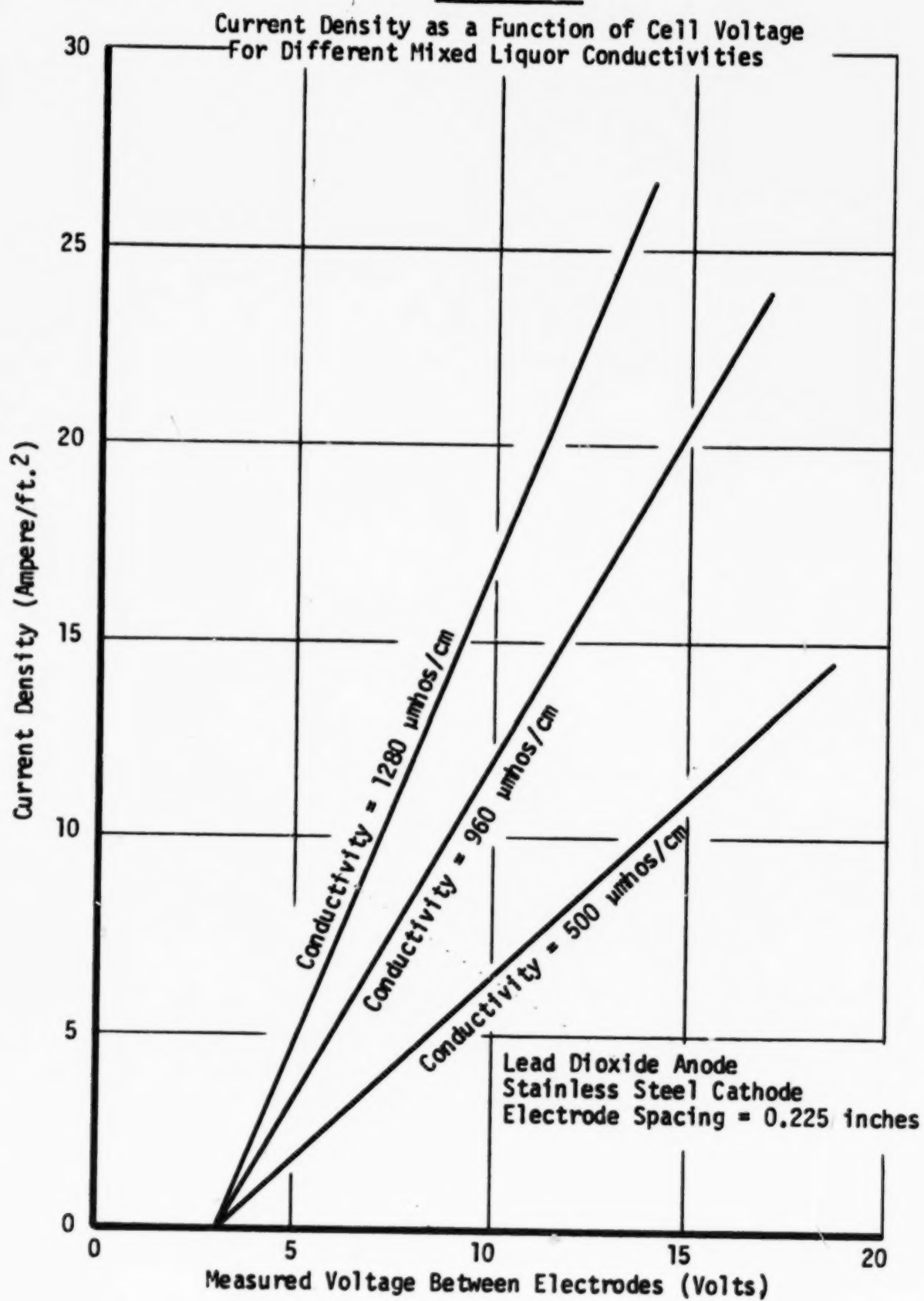
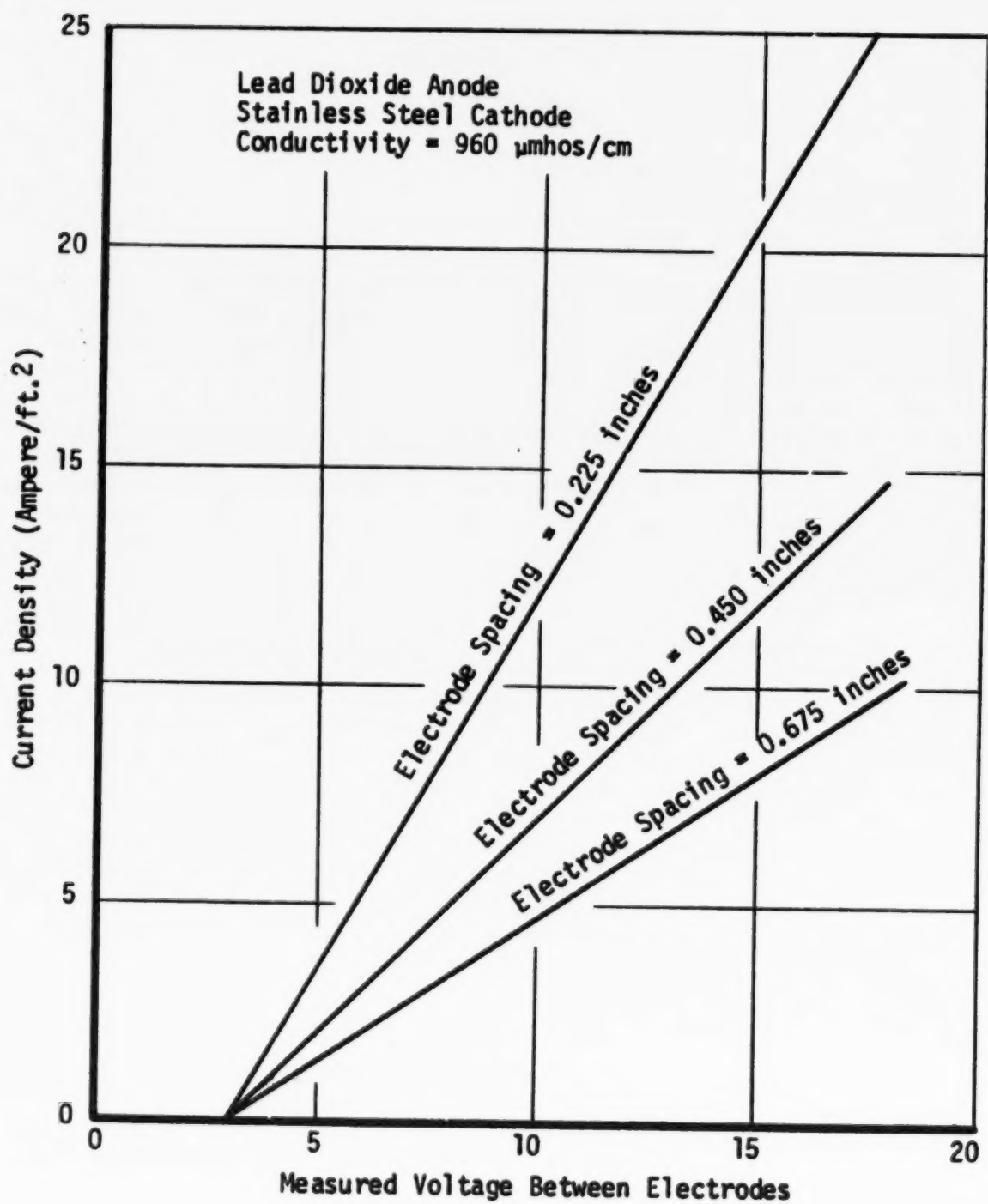


FIGURE 18
Current Density as a Function of Cell
Voltage for Different Electrode Spacings



The data presented in Figures 17 and 18 can be expressed mathematically as:

$$I_D = \frac{K g (V-3)}{S^n}$$

Where:

I_D = Current density in amperes/ft²

K = Constant

g = Conductivity in μ mhos/cm

V = Voltage in volts

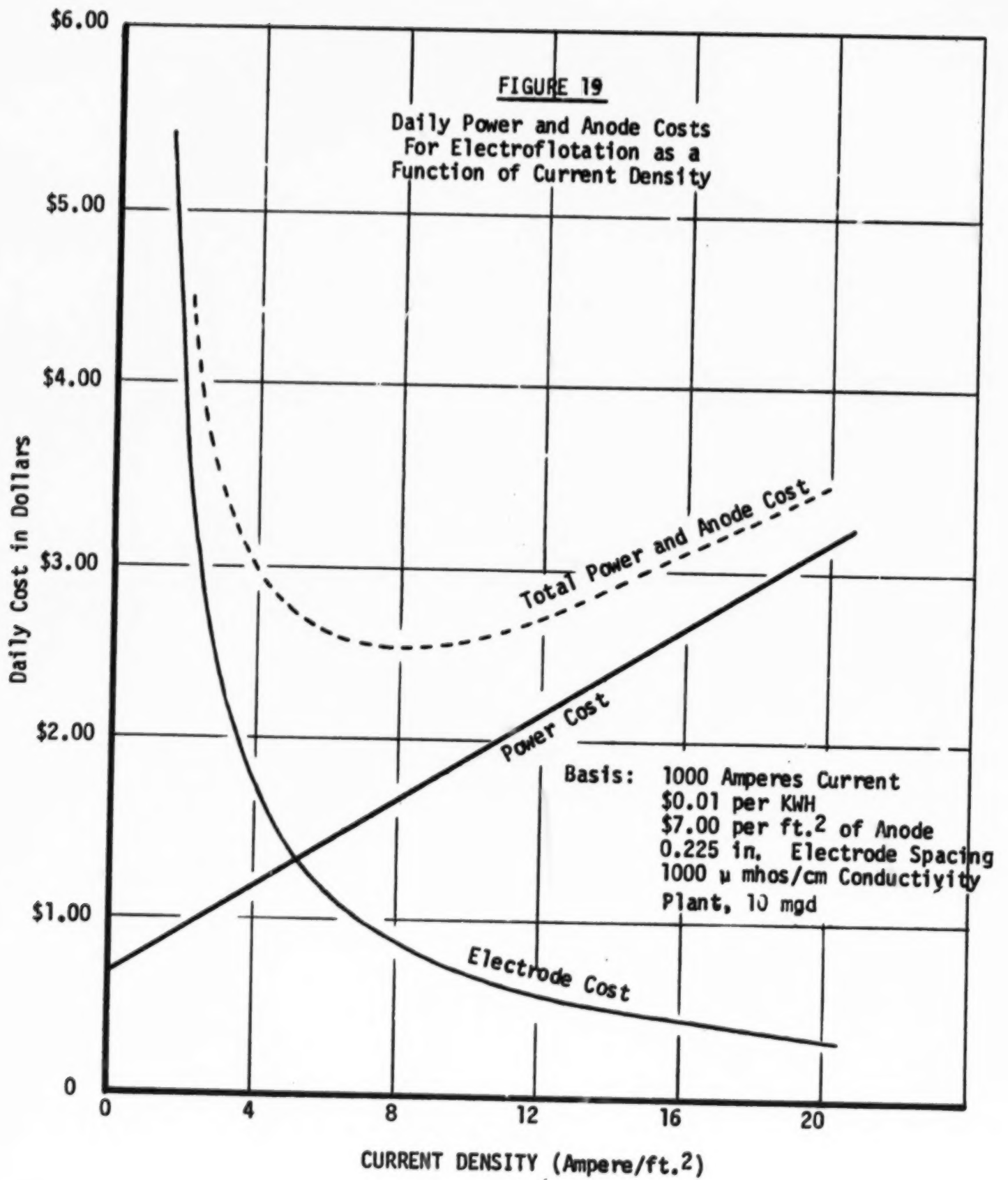
S = Electrode spacing in inches

n = Constant ≈ 0.9

For this report 0.225 inches was considered the minimum reasonable spacing because a lesser spacing would lead to undue clogging due to solids from the mixed liquor and deposits, mainly calcium carbonate, that form on the cathodes.

For a given liquor to be separated, the voltage and therefore the power cost will decrease as the current density is decreased. However, the electrode area required will increase as the current density is decreased thus increasing the electrode costs. Hence, there must be an optimum current density that will balance the cost of generating the gas bubbles with the capital cost of the electrodes.

If the operating labor, the tankage cost, and the external circuit power requirements are assumed to depend only upon the solids loading, then only the electrode costs and the intra-electrode power costs are a function of the current density. Both the daily electrode cost based upon \$7.00 per square foot for a 10 mgd plant and a life of 1000 days and the daily power cost, based upon 1000 amperes, are plotted as a function of current density in Figure 19. This figure also shows the sum of these two costs. The optimum current density is about 8 amps/square foot yielding a cost of \$2.50 per day for 1000 amperes. However, the daily cost from 6 to 10 amperes per square foot is less than \$2.60 for 1000 amperes showing the total costs to be fairly insensitive to current density near the optimum.



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SECTION VII

ECONOMIC EVALUATION

The final evaluation of any sewage treatment process is whether the cost of that particular process is competitive with other forms of treatment. For this reason, cost estimates for a 10 mgd treatment plant using the KASP were prepared for both electroflotation and gravity settling. These cost estimates are exclusive of primary treatment because the cost of primary treatment varies considerably for different industrial wastes.

Most of the unit costs used were those presented by Smith (4). The main design parameters used were 200 pounds of BOD per day per thousand cubic feet of aeration tank, 40 pounds of mixed liquor solids per day per square foot of final tank and an oxygen transfer efficiency of 15 percent at zero dissolved oxygen. Also, it was assumed that the above volumetric loading would produce a concentration of mixed liquor suspended solids of 10,000 mg per liter.

Table 3 shows a breakdown of capital, operating, and total annual costs for gravity sedimentation and flotation. A comparison shows that gravity settling requires a higher capital outlay than does treatment by electroflotation. It should be noted that the expense of the electrodes is treated not as a capital cost but, because of their short life, as an operating expense.

Electroflotation was assumed to have the same operating and maintenance costs as gravity settling for aeration, sludge collection, pumping, etc. However, electroflotation has the additional costs for power and electrodes. The added cost for these is \$2,430 per day or about 20¢ per thousand gallons. This corresponds to a cost of \$4.40 per ton of floated solids comparing favorably to the \$6 to \$15 per ton of floated solids that has been reported (5) for air flotation.

As can be seen in Table 3, the operating costs using electroflotation are about three and a half times larger than those using gravity settling and are excessive. The operating cost for the KASP using gravity settling and treating a sewage containing 250 mg/liter of BOD is about 7¢ per thousand gallons compared to 29¢ for electroflotation. It should be noted that because of the mode of operation for the KASP, these costs include the handling of waste activated sludge.

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TABLE 3

SUMMARY OF COSTS FOR 10 MGD PLANTCAPITAL COST * ($\$ \times 10^3$)

	BOD 250 mg/l	BOD 500 mg/l	BOD 750 mg/l	BOD 1000 mg/l
Gravity Sedimenta- tion	2,474	2,875	3,274	3,679
Electroflotation	1,901	2,302	2,702	3,106

OPERATING COST $\text{\$/1000 GALLON}$ **

	BOD 250 mg/l	BOD 500 mg/l	BOD 750 mg/l	BOD 1000 mg/l
Gravity Sedimenta- tion	2.2	3.2	4.2	5.1
Electroflotation	25.7	26.6	27.6	28.6

TOTAL ANNUAL COST $\text{\$/1000 Gallon}$ ***

	BOD 250 mg/l	BOD 500 mg/l	BOD 750 mg/l	BOD 1000 mg/l
Gravity Sedimenta- tion	6.7	8.4	10.0	11.5
Electroflotation	29.1	30.8	32.4	34.0

* Costs are for 1967

** Based on 1¢/KWH

*** Based on 4-1/2% interest and 25-year life

SECTION VIII

DISCUSSION

The operation of the KASP biological system using gravity settling was very effective in BOD₅ and solids removal and performed with no major difficulties. Once the air and liquid flows were set, the system required no attention except for sampling and mechanical maintenance. The biological system performed well throughout its operation except for the period of July 9th through July 11th, 1968 when the pH of the sewage ranged from 9.2 to 11.2. This high pH waste raised the pH of the mixed liquor to 9.7, which apparently killed most of the mixed liquor bio-mass because little or no active microbiological life was observed by microscopic examination.

The electroflotation system also performed well but was susceptible to power failures. On those occasions when a power failure occurred, gas was no longer generated at the electrodes and the flotation cell would fill with mixed liquor solids. When the power was returned to the electrodes, the sludge around the electrodes seemed to be so dense that these solids would not float. To resume operation, these settled solids had to be drained from the bottom of the flotation cell. Because of this apparent susceptibility to power failures, as well as the higher operational cost, electroflotation seems to be better suited to sludge concentration or some other use where such failure does not directly affect effluent quality.

The operation of the KASP showed that aerobic digestion could be obtained in the aeration tank of a completely mixed activated sludge plant at aeration times from 2 to 8 hours. This was done by having no intentional wasting of sludge and operating such that the concentration of mixed liquor solids stabilized at about 10,000 mg/liter. The KASP produced about a 90 percent reduction in BOD₅ but the KASP does have features that can limit its application.

One limitation is the low removal of TOC. Organic carbon is present in the raw waste in two forms, non-biodegradable carbon and biodegradable carbon. Non-biodegradable carbon is unaffected by microbiological activity and therefore would not be removed by the KASP or any other activated sludge process. This portion of the organic waste will pass through unchanged and therefore limit the amount of carbon that can be removed from the influent waste. In the KASP, most of the biodegradable carbon, measured as BOD₅, was readily converted to a settleable activated sludge mass and carbon dioxide allowing high removals of BOD₅. However, a portion of the settleable sludge mass cannot be biodegraded. Therefore, it cannot be oxidized and removed as carbon dioxide. In conventional activated sludge treatment, some of this non-biodegradable sludge is removed as waste activated sludge. The KASP differed from conventional activated sludge treatment in that no solids were intentionally wasted from the system. Therefore, the non-biodegradable sludge mass formed by the KASP must either remain in the aeration tank or be washed out as organic carbon in the effluent. McKinney (6) indicates that for complete oxidation systems, approximately 10 to 13 percent of the biodegradable organic matter being treated will appear in the effluent as inert solids. For the operation of the KASP, the removal of organic carbon was usually about

80 to 85 percent. The effluent from the KASP was high in turbidity and color and did not have the sparkling appearance that is observed in the effluent from a well run activated sludge plant that wastes activated sludge. The increase in color and turbidity over a conventional activated sludge plant is probably due to the added carbon carried into the effluent.

Because no waste activated sludge stream is removed from the KASP, no inorganic nutrients are removed with the waste sludge. However, in a conventional activated sludge plant inorganic nutrients are removed with waste activated sludge. Therefore, BOD removal is the only area where the KASP can equal the performance of an activated sludge plant that wastes sludge.

One logical extension of the KASP is increasing the volumetric BOD₅ loading and thereby increasing the substrate level and correspondingly the concentration of mixed liquor solids. The increased loading results in a smaller aeration tank and reduced costs. However, the BOD₅ loading can only be increased if there is sufficient aeration capacity to supply the increased oxygen demand that the increased loading would require. Therefore, the BOD loading and the steady state concentration of solids in the mixed liquor are limited by the aeration capacity. For this study, 10,000 mg/liter was thought to be a good compromise.

The KASP provides a lower removal of TOC, nitrogen, and phosphorus than can be achieved from a conventional activated sludge plant that wastes sludge, but the KASP offers other advantages. The KASP was found to be able to produce a high degree of treatment of sewage following 48 hours with no organic loading.

One possible use of the KASP that will profit from its advantages and not be hindered by its disadvantages is the treatment of high strength industrial wastes prior to their discharge into a municipal sewer. The municipal treatment plant would benefit from the reduction in BOD₅. Some of the advantages of the KASP that the industry could benefit from are given below.

The KASP provides simple operation requiring no waste sludge handling facilities. The KASP has the ability to withstand long periods of no organic loading for industries that do not work over weekends or do not have 24-hour a day production.

One last advantage of using the KASP for waste treatment at an industrial plant prior to discharge of the waste into a municipal sewer is that the cost of treatment could possibly be less than that given in this report since some forms of treatment such as preliminary treatment and chlorination could be eliminated because of the duplication of services at the municipal treatment plant.

The KASP appears to be a suitable form of waste treatment where about 90 percent removal of BOD₅ is desired and where little removal of either phosphorus or nitrogen, as well as only an 80 percent removal of organic carbon, is acceptable. For a waste containing 250 mg/liter of BOD₅, the KASP using gravity settling can meet these requirements at an estimated

cost of 7¢ per thousand gallons. With electroflotation as the method of solids separation, the KASP, with an estimated cost of 29¢ per thousand gallons, becomes a very expensive method of treatment.

An activated sludge plant such as the KASP using no intentional sludge wasting and operating on the principle of steady state concentration of active mass appears to have an application for treating industrial wastes. However, prior to the installation of a KASP process, it is desirable to operate a pilot plant to determine the necessary design parameters for each individual industrial waste because of the known difference in the BOD removal rate constants for the various wastes.

SECTION IX

ACKNOWLEDGMENT

The continuing attention, interest, and technical review and guidance of this work by Mr. Charles L. Swanson, as FWQA Project Officer, is gratefully acknowledged.

Contributing Personnel included Warren G. Palmer, M. Floyd Hobbs, James M. Rowe, Silvestre W. Sierra, and Frank F. Sako.

Appreciation is expressed also to Dr. H. S. Smith for his interest in the project.

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SECTION XI

APPENDICES

Kehr Process Operational Data

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TABLE A-I
KEHR PROCESS BOD AND TOC DATA

Date	Aeration Period	Sewage TOC (mg/l)	Effluent TOC (mg/l)	% TOC Removal	Sewage BOD ₅ (mg/l)	Effluent BOD ₅ (mg/l)	% BOD ₅ Removal
8/29/68	8 hours	764	121	84.2	1233	121	90.2
8/30/68	"	820	127	84.5	1545	94	93.9
8/31/68*	"	580	80	86.2	1113	85	92.3
9/1/68**	"	190	120	36.8	327	182	44.5
9/2/68***	"	114	113	0.7	181	97	56.2
9/3/68	"	718	76	89.4	1224	58	95.2
9/4/68	"	825	129	84.4	1248	81	93.5
9/5/68	"	882	130	85.3	1380	100	91.7
9/6/68	"	840	141	83.2	1191	156	86.7
9/7/68*	"	560	145	74.2	888	140	84.2
9/8/68**	"	78	115	(-48.4)	146	104	28.4
9/9/68	"	690	103	85.1	1098	67	93.9
9/22/67	6 hours	483	82	83.0	855	--	--
9/23/67*	"	160	63	60.6	345	--	--
9/24/67**	"	81	73	9.8	144	--	--
9/25/67	"	470	82	82.5	552	--	--
9/26/67	"	477	82	82.8	801	--	--
9/27/67	"	509	70	86.0	1038	107	89.7
9/28/67	"	316	118	62.6	558	141	74.7
9/29/67	4 hours	329	90	72.6	540	134	75.2
9/30/67*	"	161	58	63.9	177	66	62.7
10/1/67**	"	88	39	55.6	136	30	78.0
10/2/67	"	210	73	65.2	--	--	--
10/3/67	"	280	18	93.5	425	3	99.3
10/4/67	"	200	43	78.5	330	37	88.8
10/5/67	"	225	19	91.3	297	17	94.3

* Saturday
** Sunday
*** Labor Day

TABLE A-I (Continued)

KEHR PROCESS BOD AND TOC DATA

Date	Aeration Period	Sewage TOC (mg/l)	Effluent TOC (mg/l)	% TOC Removal	Sewage BOD ₅ (mg/l)	Effluent BOD ₅ (mg/l)	% BOD ₅ Removal
10/6/67	4 hours	246	61	75.2	333	45	86.5
10/7/67*	"	165	42	74.5	179	40	77.7
10/8/67**	"	75	24	68.5	110	15	86.4
10/9/67	"	180	28	84.4	127	18	86.1
10/10/67	2 hours	207	27	86.7	301	12	96.0
10/11/67	"	117	16	86.2	197	10	94.7
10/12/67	"	142	18	87.4	223	13	89.9
10/13/67	"	160	18	88.6	224	9	95.9
10/14/67*	"	132	16	87.8	201	8	95.9
10/15/67**	"	108	17	84.3	166	5	97.3
10/16/67	"	230	26	88.9	387	24	93.8
10/17/67	"	118	21	82.0	208	10	95.1
10/18/67	"	127	18	86.1	209	7	96.5
10/19/67	"	162	12	92.6	206	11	94.5

* Saturday
** Sunday

TABLE A-II
KEHR PROCESS INFLUENT
AND EFFLUENT SOLIDS DATA

Date	Aeration Period	SEWAGE		EFFLUENT		% Removal of SS
		SS (mg/l)	VSS (mg/l)	SS (mg/l)	VSS (mg/l)	
8/29/68	8 hours	266	218	90	82	66.2
8/30/68	"	230	169	88	82	61.7
8/31/68*	"	234	194	51	51	78.2
9/1/68**	"	234	196	66	57	71.8
9/2/68***	"	170	125	143	115	15.9
9/3/68	"	206	172	132	94	35.9
9/4/68	"	292	249	166	151	43.2
9/5/68	"	384	316	144	124	62.5
9/6/68	"	320	269	212	184	33.8
9/7/68*	"	136	116	210	194	(-54.4)
9/8/68**	"	80	63	192	162	(-140.0)
9/9/68	"	218	160	136	118	37.6
9/22/68	6 hours	216	157	76	74	64.8
9/23/68*	"	114	98	38	35	66.7
9/24/68**	"	103	85	24	20	76.7
9/25/68	"	83	71	45	37	45.8
9/26/68	"	252	200	48	39	81.0
9/27/68	"	262	236	54	50	79.4
9/28/68	"	154	128	72	64	53.2
9/29/68	4 hours	106	101	70	51	33.6
9/30/68*	"	124	100	40	31	67.7
10/1/68**	"	82	66	25	23	69.5
10/2/68	"	132	124	58	44	56.1
10/3/68	"	116	95	17	13	85.3
10/4/68	"	150	120	37	36	75.3
10/5/68	"	153	110	19	18	87.6
10/6/68	"	125	88	52	43	58.4
10/7/68*	"	105	75	27	22	74.3
10/8/68**	"	110	99	18	17	83.6
10/9/68	"	169	125	27	24	84.0
10/10/68	2 hours	138	108	27	24	80.4
10/11/68	"	143	98	21	18	85.3
10/12/68	"	153	103	30	25	80.4
10/13/68	"	126	75	15	12	88.1
10/14/68*	"	135	103	12	9	91.1
10/15/68**	"	147	121	13	11	91.2
10/16/68	"	174	129	23	21	86.8
10/17/68	"	109	78	24	20	78.0
10/18/68	"	118	80	12	11	89.8
10/19/68	"	187	138	10	7	94.6

* Saturday
** Sunday
*** Labor Day

SS - Suspended Solids
VSS - Volatile Suspended Solids

TABLE A-III
KEHR PROCESS BIOLOGICAL SOLIDS DATA

Date	Aeration Period	MIXED LIQUOR SOLIDS DATA				RETURN SLUDGE SOLIDS DATA			
		SS*	VSS*	SVI	SS*	VSS*	TS	TVS	
8/29/68	8 hours	12,190	11,150	882	26,600	23,940	--	--	
8/30/68	"	10,930	9,720	91	9,840	8,740	--	--	
8/31/68**	"	7,360	6,660	133	22,880	20,630	--	--	
9/1/68***	"	7,090	6,440	140	23,350	21,690	--	--	
9/2/68****	"	5,750	4,380	174	9,530	8,600	--	--	
9/3/68	"	7,380	6,660	135	11,750	10,470	--	--	
9/4/68	"	7,200	6,450	138	7,760	6,980	--	--	
9/5/68	"	6,030	5,390	165	6,340	5,690	--	--	
9/6/68	"	6,070	5,440	164	9,740	8,750	--	--	
9/7/68**	"	5,080	4,580	196	11,175	9,875	--	--	
9/8/68***	"	4,400	3,980	226	4,630	4,180	--	--	
9/9/68	"	6,220	5,580	160	17,520	15,670	--	--	
9/22/67	6 hours	11,770	--	85	--	--	1.372%	1.256%	
9/23/67**	"	11,300	10,640	88	6,990	6,570	0.7775%	0.7162%	
9/24/67***	"	4,540	4,105	--	5,170	4,675	--	--	
9/25/67	"	8,590	7,800	116	18,140	16,595	--	--	
9/26/67	"	10,360	9,395	97	27,970	25,110	--	--	
9/27/67	"	5,520	5,000	174	--	--	0.837%	0.713%	
9/28/67	"	5,810	5,290	165	--	--	--	--	
9/29/67	"	7,300	6,620	136	--	--	1.127%	1.004%	
9/30/67**	"	4,950	4,765	198	5,310	4,080	0.5848%	0.510%	
10/1/67***	"	4,940	4,430	198	5,990	5,340	0.604%	0.520%	
10/2/67	"	6,814	6,115	145	10,920	9,845	--	--	
10/3/67	"	6,150	5,495	159	9,300	8,270	0.881%	0.768%	
10/4/67	"	8,110	7,245	123	13,860	12,510	--	--	

* Values are given in mg/liter

** Saturday

*** Sunday

**** Labor Day

TABLE A-III (Continued)
KEHR PROCESS BIOLOGICAL SOLIDS DATA

Date	Aeration Period	MIXED LIQUOR SOLIDS DATA				RETURN SLUDGE SOLIDS DATA			
		SS*	VSS*	SVI	SS*	VSS*	TS	TVS	
10/5/67	4 hours	7,860	6,340	126	8,760	7,860	0.8937%	0.7680%	
10/6/67	"	4,280	3,800	225	7,540	6,705	--	--	
10/7/67**	"	9,120	8,185	109	9,760	8,680	0.9975%	0.8814%	
10/8/67***	"	6,875	6,040	144	11,740	10,420	--	--	
10/9/67	"	6,040	5,270	163	12,070	10,555	--	--	
10/10/67	2 hours	9,310	8,100	107	17,905	15,925	--	--	
10/11/67	"	5,315	4,675	183	10,230	8,990	--	--	
10/12/67	"	9,545	8,350	105	22,830	20,095	--	--	
10/13/67	"	8,610	7,425	115	18,160	15,890	--	--	
10/14/67**	"	9,275	8,005	107	30,900	28,600	--	--	
10/15/67***	"	9,765	8,385	102	34,420	32,050	--	--	
10/16/67	"	7,595	6,490	130	14,755	12,685	--	--	
10/17/67	"	8,115	6,930	121	18,835	16,260	--	--	
10/18/67	"	3,830	3,225	227	19,860	17,120	--	--	
10/19/67	"	8,850	7,505	112	33,580	30,710	--	--	

* Values are given mg/liter
** Saturday
*** Sunday

TABLE A-IV
KEHR PROCESS LOADING FACTORS

Date	Aeration Period	#BOD	#BOD	#BOD
		#SS-Day	#VSS-Day	10 ³ ft ³ -Day
8/29/68	8 hours	.303	.332	230
8/30/68	"	.424	.477	289
8/31/68*	"	.460	.509	211
9/1/68**	"	.138	.152	61
9/2/68***	"	.094	.130	34
9/3/68	"	.498	.556	229
9/4/68	"	.520	.580	233
9/5/68	"	.686	.768	258
9/6/68	"	.588	.656	223
9/7/68*	"	.524	.582	166
9/8/68**	"	.099	.110	27
9/9/68	"	.530	.590	205
9/22/67	6 hours	.290	.321	214
9/23/67*	"	.122	.129	86
9/24/67**	"	.127	.140	36
9/25/67	"	.257	.283	138
9/26/67	"	.309	.340	200
9/27/67	"	.752	.830	260
9/28/67	"	.384	.422	140
9/29/67	4 hours	.444	.489	202
9/30/67*	"	.214	.223	66
10/1/67**	"	.165	.184	51
10/2/67	"	-	-	-
10/3/67	"	.414	.464	159
10/4/67	"	.244	.273	124
10/5/67	"	.227	.281	111
10/6/67	"	.467	.526	125
10/7/67*	"	.118	.131	67
10/8/67**	"	.096	.109	41
10/9/67	"	.126	.144	476
10/10/67	2 hours	.387	.446	226
10/11/67	"	.445	.505	148
10/12/67	"	.280	.320	167
10/13/67	"	.312	.361	168
10/14/67*	"	.260	.301	151
10/15/67**	"	.204	.236	124
10/16/67	"	.611	.716	290
10/17/67	"	.308	.360	156
10/18/67	"	.655	.778	157
10/19/67	"	.278	.329	155

* Saturday

** Sunday

*** Labor Day

Note: Pounds of BOD are #BOD₅ fed per day. Pounds of solids and volumes are for the aeration tank only.

TABLE A-V
CONCENTRATION OF TOC AND BOD₅ IN
FILTERED* AND UNFILTERED SAMPLES
OF KEHR SEWAGE AND EFFLUENT

SEWAGE				
Date	Filtered* TOC (mg/liter)	Unfiltered TOC (mg/liter)	Filtered* BOD ₅ (mg/liter)	Unfiltered BOD ₅ (mg/liter)
9/1/68	134	190	270	327
9/4/68	730	825	1131	1248
9/5/68	865	882	1152	1380
9/6/68	665	840	1122	1191
9/7/68	500	560	759	888
9/8/68	54	78	97	146
9/9/68	590	690	948	1098

EFFLUENT				
9/1/68	96	120	160	182
9/4/68	48	129	51	81
9/5/68	80	130	96	100
9/6/68	65	141	88	156
9/7/68	70	145	119	140
9/8/68	38	115	45	104
9/9/68	44	103	49	67

* Samples filtered through Whatman GFC Glass Filter Paper.

TABLE A-VI
 CONCENTRATION OF TOTAL PHOSPHATE AND ORGANIC
 NITROGEN IN FILTERED* AND UNFILTERED SAMPLES
 OF KEHR SEWAGE AND EFFLUENT

SEWAGE				
Date	Filtered* P04 (mg/liter)	Unfiltered P04 (mg/liter)	Filtered* Organic Nitrogen (mg/liter)	Unfiltered Organic Nitrogen (mg/liter)
8/28/68	25.8	54.0	11.4	21.5
8/29/68	--	--	10.8	18.6
9/4/68	23.7	31.1	13.0	19.5
9/8/68	56.2	58.9	--	--

EFFLUENT				
8/29/68	--	--	2.1	9.0
9/4/68	22.0	26.1	2.3	10.5
9/8/68	21.8	29.7	--	--

* Samples filtered through Whatman GFC Glass Filter Paper

TABLE A-VII
KEHR PROCESS pH DATA

Date	Time	pH of The Sewage	pH of The Mixed Liquor	pH of The Effluent
8/29/68	AM	9.00	7.09	7.11
	PM	8.50	7.30	7.03
8/30/68	AM	8.73	7.69	7.30
	PM	8.40	--	7.22
8/31/68	AM	8.28	7.50	7.27
9/1/68	AM	7.10	7.58	6.90
9/2/68	AM	7.82	7.00	7.02
	PM	7.32	--	7.10
9/3/68	AM	9.35	7.71	7.23
	PM	9.25	--	7.21
9/4/68	AM	8.67	--	7.20
	PM	9.63	7.20	7.11
9/5/68	AM	9.12	7.70	6.78
	PM	9.09	--	7.03
9/6/68	AM	9.31	7.52	7.30
	PM	8.89	--	6.88
9/7/68	AM	8.00	7.50	6.70
9/8/68	AM	7.40	8.00	7.15
9/9/68	AM	9.02	7.60	7.12
	PM	9.02	--	7.02

TABLE A-VIII
DATA FOR THE ELECTROFLOTATION OF KEIR MIXED LIQUOR

Run No.	MLSS mg/l	SVI	Electrode Current (amps)	Mixed Liquor Flow l/min	Ratio of MLSS To Effluent SS	cc of Gas Produced per gram of MLSS *
1	3,555	241	10	1.43	106	20.6
2	3,535	241	10	1.54	200	19.2
3	3,405	247	8.5	1.44	111	17.6
4	3,425	251	4.7	1.48	75	9.7
5	3,170	281	8	1.40	170	16.8
6	3,375	292	5.4	1.33	173	13.8
7	3,480	258	10	1.43	172	21.0
8	3,230	285	8.6	1.43	86	19.4
9	3,460	265	7.3	1.43	113	15.4
10	3,955	234	8	1.20	150	17.6
11	3,785	244	8	1.20	121	17.1
12	3,360	247	10	4.50	49	11.6
13	6,470	147	10	2.86	11	5.6
14	4,675	195	10	1.41	100	15.8
15	3,910	---	7.4	1.41	61	14.0
16	3,210	88	10	1.28	32	25.5
17	2,120	88	10	3.53	16	14.0
18	4,300	51	8.8	2.00	9	10.7
19	3,020	112	10.5	1.78	20	20.4
20	3,250	129	10.5	1.21	33	11.0
21	5,450	132	10	0.95	33	20.1
22	5,480	148	9.4	0.96	57	18.7
23	5,190	118	10.5	1.52	24	13.9
24	10,080	100	9.9	0.88	44	11.7
25	8,370	---	9.9	1.13	8	10.0
26	6,480	153	9.3	0.84	40	17.9
27	7,320	134	10.2	1.76	11	8.2

* Based upon 10.43 cc/min for 1 ampere.

TABLE A-IX
SUMMARY SHEET FOR DIURNAL VARIATION STUDY

Date	Time	SS	VSS	COD	BOD	PO ₄	NO ₃ *	NO ₂ *	NH ₃ *	O - N	TOC
8-22-67	12-4 AM	260	236	2540	1899	19.8	3.90	0	5.53	23.15	908
"	4-8 AM	104	94	1260	969	15.0	3.53	0	1.60	12.38	508
"	8-12 AM	60	60	1090	1104	17.4	3.70	~0	9.84	15.75	421
"	12-4 PM	148	130	1845	1152	29.5	1.25	0	6.99	17.06	632
"	4-8 PM	144	119	2270	1119	25.6	1.00	0	5.97	15.58	568.4
"	8-12 PM	268	236	2235	1359	21.5	1.05	.0058	6.99	19.80	725.9
8-23-67	12-4 AM	280	246	2130	1572	16.6	1.45	0	2.91	18.23	727.2
"	4-8 AM	84	68	914	675	10.0	1.20	.026	3.61	7.57	319.5
"	8-12 AM	200	75	1121	750	18.0	1.35	0	9.26	12.23	393
"	12-4 PM	138	102	1495	843	27.0	1.45	0	5.10	13.31	521
"	4-8 PM	140	114	1470	822	23.1	1.05	0	4.08	14.04	510
"	8-12 PM	218	178	1840	1083	22.7	1.05	0	9.09	16.44	627
8-24-67	12-4 AM	318	274	2040	1119	26.4	1.00	0	3.09	20.61	674
"	4-8 AM	171	56	812	435	20.2	1.25	.0060	1.92	10.19	276
"	8-12 AM	70	58	1062	609	19.7	1.55	.0072	4.37	12.81	343
"	12-4 PM	206	172	1493	912	26.7	1.70	0	7.43	13.98	542
"	4-8 PM	248	208	1866	1143	28.6	1.15	.0012	6.26	16.60	585
"	8-12 PM	470	417	2098	1548	33.3	1.15	0	16.31	37.27	769

NOTE: All Values are in mg/liter.

* Values given as mg/liter of N

TABLE A-X
KEHR PROCESS INFLUENT AND
EFFLUENT PHOSPHATE CONCENTRATIONS

Date	Aeration Period	Total Concentration of Phosphate in mg/liter*	
		Sewage	Effluent
8/29/68	8 hours	19.2	14.2
8/30/68	"	58.0	18.5
8/31/68**	"	41.8	18.5
9/1/68***	"	50.7	23.0
9/2/68****	"	44.4	36.4
9/3/68	"	--	35.3
9/4/68	"	31.1	26.1
9/5/68	"	32.0	19.9
9/6/68	"	26.0	27.0
9/7/68**	"	20.5	17.5
9/8/68***	"	58.9	29.7
9/9/68	"	41.1	24.4
9/22/67	6 hours	28.6	14.2
9/23/67**	"	35.8	11.6
9/24/67***	"	26.6	21.8
9/25/67	"	24.8	23.8
9/26/67	"	20.6	17.6
9/27/67	"	23.4	18.4
9/28/67	"	42.4	28.6
9/29/67	4 hours	50.0	32.6
9/30/67**	"	57.2	29.4
10/1/67***	"	23.8	26.4
10/2/67	"	54.2	51.4
10/3/67	"	51.2	10.8
10/4/67	"	30.2	36.6
10/5/67	"	33.4	21.6
10/6/67	"	40.4	25.2
10/7/67**	"	77.6	32.6
10/8/67***	"	22.6	31.0
10/9/67	"	38.0	30.6
10/10/67	2 hours	28.6	25.6
10/11/67	"	23.4	23.6
10/12/67	"	29.4	22.4
10/13/67	"	27.4	30.2
10/14/67**	"	28.6	27.2
10/15/67***	"	29.2	26.2
10/16/67	"	29.2	29.4
10/17/67	"	28.6	25.2
10/18/67	"	28.8	28.8
10/19/67	"	27.2	23.8

* As PO_4
** Saturday
*** Sunday
**** Labor Day

TABLE A-XI
NITROGEN DATA FOR KEHR PROCESS SEWAGE

Date	Aeration Period	NH ₃ *	Organic-N*	NO ₂ *	NO ₃ *	Total N*
8/29/68	8 hours	6.65	18.60	--	1.35	26.60
8/30/68	"	4.60	16.80	--	0.88	22.28
8/31/68**	"	5.36	15.10	--	1.10	21.56
9/1/68***	"	5.65	10.90	--	0.72	17.27
9/2/68****	"	28.00	15.10	--	0.38	43.48
9/3/68	"	9.30	20.70	--	0.50	30.50
9/4/68	"	7.57	19.50	--	0.28	27.35
9/5/68	"	6.41	--	--	2.36	--
9/6/68	"	6.70	21.30	--	1.54	29.54
9/7/68**	"	6.99	13.10	--	1.55	21.64
9/8/68***	"	6.99	6.41	--	1.15	13.09
9/9/68	"	8.30	17.80	--	0.95	27.05
9/22/67	6 hours	7.0	13.1	--	1.00	21.10
9/23/67**	"	9.3	12.1	--	--	21.40
9/24/67***	"	29.9	11.1	--	--	41.00
9/25/67	"	14.1	13.6	--	0.98	26.68
9/26/67	"	8.6	16.6	--	0.96	28.68
9/27/67	"	6.9	16.2	--	0.82	23.92
9/28/67	"	10.0	10.1	--	0.54	20.64
9/29/67	4 hours	12.0	10.1	--	0.85	22.95
9/30/67**	"	24.4	10.8	--	0.18	35.38
10/1/67***	"	27.5	10.2	--	0.08	37.78
10/2/67	"	18.1	8.9	--	--	27.00
10/3/67	"	14.6	11.1	--	--	25.70
10/4/67	"	15.6	7.5	--	--	23.10
10/5/67	"	16.0	9.8	--	--	25.80
10/6/67	"	17.2	11.3	--	--	28.50
10/7/67**	"	23.0	10.0	--	--	33.00
10/8/67***	"	32.2	10.7	--	--	42.90
10/9/67	"	34.4	9.1	.01	--	43.51
10/10/67	2 hours	21.9	11.3	.01	0.16	33.37
10/11/67	"	20.3	10.3	Trace	--	30.60
10/12/67	"	20.6	13.0	--	0.19	33.79
10/13/67	"	15.6	3.8	Trace	0.78	20.18
10/14/67**	"	24.0	10.3	Trace	0.13	34.43
10/15/67***	"	108.2	9.6	--	--	117.80
10/16/67	"	21.6	6.4	Trace	1.36	33.62
10/17/67	"	15/3	11.1	--	0.92	27.32
10/18/67	"	14.3	10.5	--	0.92	25.72
10/19/67	"	19.7	11.1	--	0.92	31.72

* Values given are in mg/liter as Nitrogen
 ** Saturday
 *** Sunday
 **** Labor Day

TABLE A-XII
NITROGEN DATA FOR KEHR PROCESS EFFLUENT

Date	Aeration Period	NH ₃ *	Organic-N*	NO ₂ *	NO ₃ *	Total N*
8/29/68	8 hours	--	9.04	--	0.20	9.24
8/30/68	"	--	7.05	--	0.18	7.23
8/31/68**	"	--	10.00	--	0.10	10.10
9/1/68***	"	--	5.45	--	0.10	5.55
9/2/68****	"	--	12.20	--	0.10	12.30
9/3/68	"	--	8.40	--	0.06	8.46
9/4/68	"	--	10.50	--	0.35	10.85
9/5/68	"	--	--	--	0.60	--
9/6/68	"	--	11.07	--	0.29	11.36
9/7/68**	"	--	10.77	--	--	10.77
9/8/68***	"	--	9.61	--	0.31	9.91
9/9/68	"	0.5	8.90	--	0.29	9.69
9/22/67	6 hours	1.2	7.2	--	--	8.40
9/23/67**	"	--	5.4	--	--	5.40
9/24/67***	"	2.3	4.3	--	--	6.60
9/25/67	"	9.8	4.0	--	0.18	13.98
9/26/67	"	4.8	5.2	--	0.36	10.36
9/27/67	"	2.8	5.2	--	0.22	8.22
9/28/67	"	3.1	5.9	--	0.40	9.40
9/29/67	4 hours	2.0	6.4	--	--	8.40
9/30/67**	"	1.2	4.2	--	0.22	5.62
10/1/67***	"	11.7	3.5	--	--	15.20
10/2/67	"	15.7	5.2	Trace	--	20.90
10/3/67	"	7.0	2.3	Trace	--	9.30
10/4/67	"	4.4	4.2	Trace	--	8.60
10/5/67	"	10.3	2.0	Trace	--	12.30
10/6/67	"	11.6	5.4	Trace	--	17.00

* Values given are in mg/liter as Nitrogen
 ** Saturday
 *** Sunday
 **** Labor Day

TABLE A-XII (Continued)

NITROGEN DATA FOR KEHR PROCESS EFFLUENT

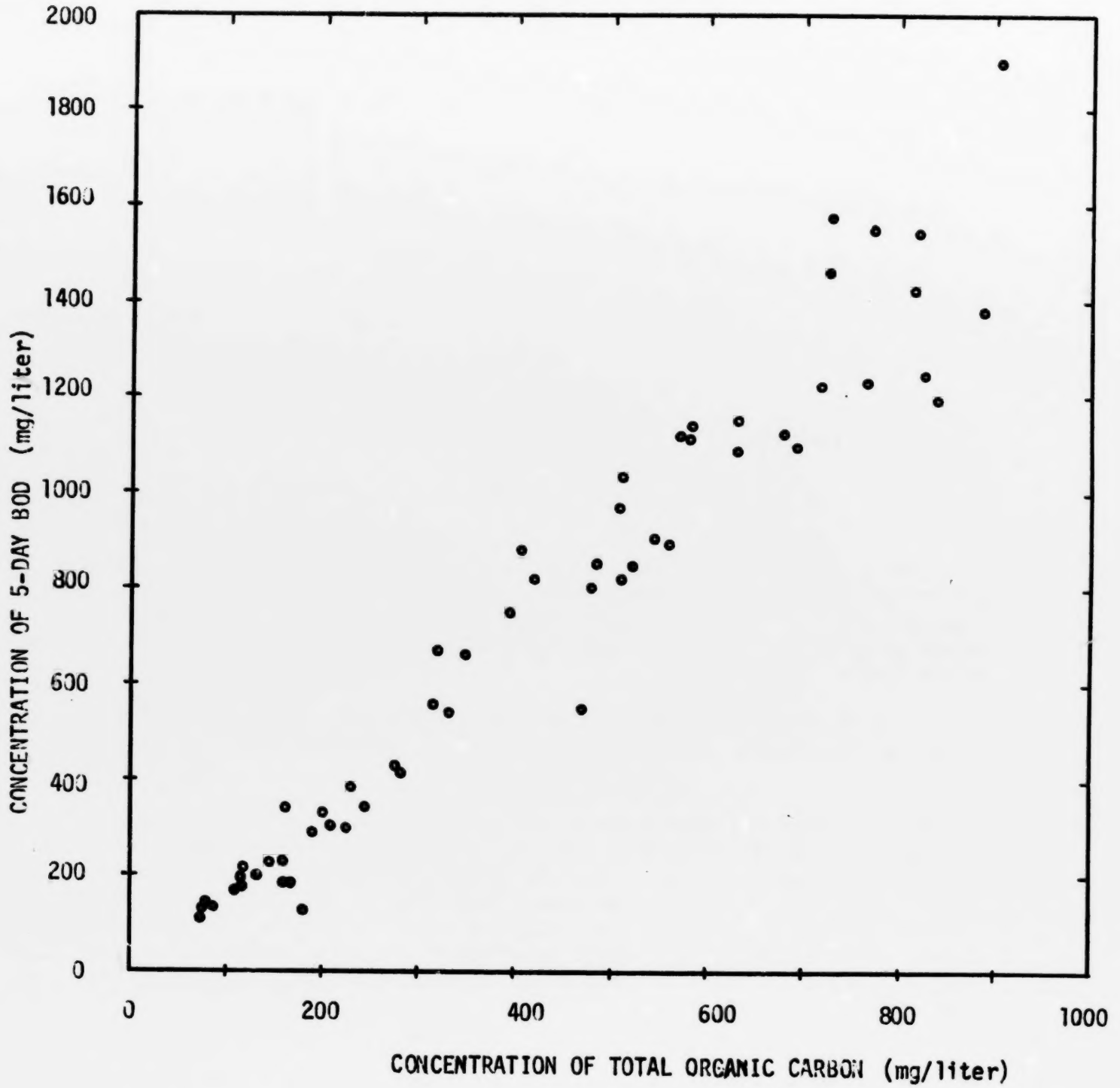
Date	Aeration Period	NH ₃ *	Organic-N*	NO ₂ *	NO ₃ *	Total N*
10/7/67**	4 hours	6.5	3.2	Trace	--	9.70
10/8/67***	"	23.7	2.7	Trace	--	26.40
10/9/67	"	27.0	3.2	0.01	--	30.21
10/10/67	2 hours	16.8	11.8	--	--	28.60
10/11/67	"	15.0	3.3	Trace	--	18.30
10/12/67	"	16.8	3.3	Trace	0.12	20.22
10/13/67	"	16.3	2.3	--	--	18.60
10/14/67**	"	14.5	2.4	Trace	--	16.90
10/15/67***	"	26.8	2.0	--	--	28.80
10/16/67	"	23.8	3.2	--	0.06	27.06
10/17/67	"	10.1	3.5	--	--	13.60
10/18/67	"	13.4	2.0	--	0.07	15.47
10/19/67	"	13.7	1.7	--	0.06	15.46

* Values given are in mg/liter as Nitrogen

** Saturday

*** Sunday

FIGURE A-1
CORRELATION OF THE BOD₅
WITH THE TOC FOR
KEHR PROCESS SEWAGE



Electroflotation Theory

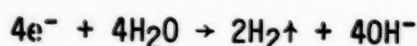
Flotation is a unit operation for separating two phases by introducing gas bubbles which adhere to one phase causing a decrease in the apparent density of that phase such that it will rise. Several methods which have been used for introducing the gas are summarized by Virablik (7). The gas used in electroflotation consists of hydrogen and oxygen produced by the electrolysis of water.

The chemical reactions occurring at the electrodes to produce these gases are shown below:

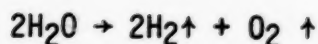
Anode Reaction:



Cathode Reaction:



Total Reaction:



From these reactions, it can be seen that for each 4 electrons of current passed between the electrodes, one molecule of oxygen and two molecules of hydrogen are formed. Or in more convenient terms, 0.174 cc of gas, measured at standard temperature and pressure, are produced by each coulomb of current.

Electrolysis of water produces small gas bubbles with diameters of the order of 100 microns that are formed at the electrodes and rise as fine mist.

Electroflotation has been considered for the separation of the biological floc from mixed liquor because bubbles from the electrodes, when contacted with mixed liquor, attach themselves to the individual floc particles causing the floc to rise. The upward velocity of the floc and attached bubbles is much higher than the settling velocity of the floc particles alone. This allows a more rapid separation than with sedimentation and can also yield a higher concentration of solids in the thickened stream than with sedimentation.

The concentration of suspended solids in the effluent tends to decrease as more of the mixed liquor solids are floated. How well the mixed liquor solids are floated depends upon the number of bubble-solid attachments that take place. As either the concentration of flocs or the concentration of gas bubbles are increased, the probability of attachment also increases. This can be expressed mathematically, assuming that

each increment of gas per gram of solids creates a change in solids concentration proportional to the concentration of solids which the gas contacts:

Then: $dC = kCdX$ (1)

Where: C = Concentration of solids below the sludge blanket
 X = Volume of gas per unit mass of sludge
 k = Constant

Integrating: $\ln \frac{C_1}{C_2} = kX_t$ (2)

Where: C_1 = The solids concentration in the feed
 C_2 = The solids concentration in the effluent
 X_t = The total gas produced per gram of solids

To determine whether performance of electroflotation is described by this model, the logarithm of the ratio of feed to effluent suspended solids should be plotted as a function of the gas production per gram of solids. If a straight line results then this model can be used to describe the performance of the electroflotation cell.

1	Accession Number	2	Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
	W		O5D	
5	Organization FMC Corporation/Central Engineering Laboratories P. O. Box 580 Santa Clara, California 95052			
6	Title Cannery Waste Treatment-Kehr Activated Sludge			
10	Author(s) Robert A. Fisher		16	Project Designation 12060 EZP
			21	Note
22	Citation			
23	Descriptors (Starred First) Cannery Wastes Industrial Waste Treatment *Activated Sludge Process Aerobic Digestion Electroflotation			
25	Identifiers (Starred First)			

27 **Abstract:** The Kehr Activated Sludge Process (KASP), as practiced at FMC Corporation's Central Engineering Laboratories, uses a completely mixed aeration tank with no intentional sludge wasting. The concentration of mixed liquor suspended solids was allowed to stabilize at some value as a result of cellular synthesis, endogenous loss, and washout in the effluent. The concentration of mixed liquor suspended solids ranged from 4,000 to 12,000 mg/liter. The BOD₅ of domestic sewage and cannery wastes varied from 200 to 2000 mg/liter. Removals obtained were 80 percent reduction in the concentration of total organic carbon and a 90 percent reduction in the concentration of BOD₅. The process was able to undergo a 48-hour period of no organic loading with no loss of treatment efficiency when the organic load was returned. The KASP appears to have an application for the pretreatment of industrial wastes prior to discharge to a municipal sewer. The KASP, when used in this manner, could handle intermittent waste discharge, produce 90 percent BOD₅ removal and provide aerobic digestion within the aeration tank. Exclusive of any primary treatment, the cost of treating 10 mgd of a waste containing 250 mg/liter of BOD₅ using this high solids activated sludge process is about 7¢ per thousand gallons using gravity settling and about 29¢ per thousand gallons using electroflotation. The cost of pretreating 1 mgd of a waste containing 2,000 mg/liter BOD is about 28¢ per thousand gallons exclusive of primary treatment. The report was submitted in fulfillment of Grant 12060 EZP between the Federal Water Quality Administration and the FMC Corporation.

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